Analysing the business impact of vertical roller technology in the mining sector

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Mini-dissertation accepted in fulfillment of the requirements for the degree Master of *Business Administration* at the North-West University

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Graduation: May 2022
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DECLARATION

I, ML Kau, solemnly declare that this research paper is my own work and is carried out in partial fulfilment of the requirements of the degree Master of Business Administration at the North-West University, and it has not been submitted to any institution for any examination.

Motlalepula Lawrence Kau

Date: 17 November 2021

ACKNOWLEDGEMENTS

I dedicate this research to my partner, Mamokete Pule, my family, my daughter Reitumetse Kau, nieces and nephews (Maipato, Mpho, Lebohang, Katleho, Mahlatse and Thateho), my grandparents in heaven, Richard Kau and Lydia Kau, for the support they gave since I started school at the age of six. I wish they were still alive to see the progress I made in life. In the name of the Father, the Son, and the Holy Spirit, Amen.

Special thanks to my study leader, Dr Johan Jordaan for the support he gave during this study.

To my colleagues, and senior management of the organisation, Mr Coenraad Calitz and Mr Kevin Carlise, thank you for the advice and support you gave me to pursue an MBA degree.

I dedicate this research to my grandparents in heaven, may their souls continue to rest in peace.

ABSTRACT

In the mining industry, higher production has an advantage in terms of costs. The higher the production, the lower the unit cost of production. Fixed costs in mining industries are mostly associated with direct production costs and manpower costs, including overtime. Unexpected vertical roller mill downtime has a huge impact on business profitability.

Despite the beneficial effect on profits by surging commodity prices and numerous cost-cutting exercises, mining businesses are under pressure. The COVID-19 pandemic has shaken the mining business worldwide. Restriction protocols in the mining business caused production to be shut down across multiple markets.

Vertical roller mill (VRM) originated from Japan and was designed by Tower Mill Kobuta Corporation in the 1950s. Vertical roller mill downtime has a huge impact on a business. Downtime creates direct costs to businesses, such as charges on late deliveries to customers and sometimes, if a contract is in place, customers have the right to sue the business. In the case of downtime, profits can be lost due to substitution products, low quality, or the frequent need for vertical roller mill repairs.

Reliability-centred maintenance (RCM) is a tool that identifies productive and effective preventative maintenance tasks for any specific piece of equipment with specific standard working instructions, for setting up intervals between maintenance activities.

Equipment spare parts are crucial for every business to ensure the smooth operation of critical equipment. In the mining industry, critical spares are kept to reduce the financial and commercial cost of downtime.

The objective of predictive maintenance is simply to warrant proactive scheduling of remedial work and prevent unexpected equipment downtime. Accurate results can only be obtained when the equipment is running. This can be achieved by connecting sensors to the equipment to record operating metrics such as temperature and control voltage to give warning of possible future failures.

Condition monitoring is critical for the success of a preventive maintenance programme. When condition monitoring is implemented successfully, the preventive maintenance programme runs smoothly.

KEYWORDS

Vertical roller mill technology, reliability-centred maintenance, spare parts, computerised maintenance management system

LIST OF ABBREVIATIONS

Abbreviations	**Meaning**
CM	Condition monitoring
CMMS	Computerised maintenance management system
COQ	Cost of quality
DWC	Days working capital
FMECA	Failure mode effects and criticality analysis
GDP	Gross domestic product
ISO	International organisation standard
MCSA	Minerals Council of South Africa
MTBF	Mean time between failures
MTTR	Mean time to repair
NASA	National Aeronautics and Space Administration
NICD	National Institute of Communicable Diseases
OEE	Original equipment effectiveness
OEM	Original equipment manufacturer

RCFA	Root cause failure analysis
RCM	Reliability-centred maintenance
ROI	Return on investment
SPSS	Statistical Package for Social Science
TQM	Total quality management
QMS	Quality management system
VRM	Vertical roller mill
WHO	World Health Organisation

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1: INTRODUCTION TO RESEARCH PROBLEM

1.1 INTRODUCTION

This study focuses on vertical roller mill technology in the mining industry. It is a comparative study between various business units within one organisation.

Chapter 1 gives the background, the problem statement of the study, research objectives, research methodology, population and sampling, research limitations and assumptions. The structure of the study is also outlined in this chapter.

1.2 BACKGROUND

The mining process has several stages that the product needs to pass through to get from being solid ore to being a refined product that can be sold to a consumer. One of the steps in the mining process is the process of grinding ore into a finer product so that this finer product can be chemically refined further. This is achieved by various milling technologies. Due to the abrasive nature of the ore, maintenance cost and downtime to do maintenance are notable constraints on the throughput of mills. The objective of this study is to analyse the impact of the maintenance of roller mill technology on output and cost in the mining industry.

In the mining industry, higher production has an advantage in terms of costs. The higher the production, the lower the unit cost of production. Fixed costs in mining industries are mostly associated with operating costs such as mining costs and manpower costs (including overtime). Unexpected vertical roller mill downtime has a huge impact on business profitability.

1.3 RESEARCH PROBLEM

Vertical roller mills have a huge impact on the business when they are down due to a breakdown or when they are producing scrap or product that needs to be reworked. Because of fierce competition in the market, customers can easily be lost due to late deliveries or when the product does not meet customers' specifications. Therefore, the availability and reliability of vertical roller mills are crucial to the business.

Vertical roller mills have become the standard equipment for raw materials grinding in the cement and minerals industries, although many cement manufacturers are still favouring ball mills in their operations. The cost of downtime is constantly changing

with economic conditions, but the real effects of downtime on output have not been quantified lately. This study endeavours to do that. The research question that this study attempts to answer is: What maintenance strategy can be used to increase the reliability and availability of vertical roller mill technology at the lowest total cost?

The mining sector plays an important role in the South African economy. In 2008, the mining sector contributed almost 9.5% of South Africa's gross domestic product (GDP). The sector is divided into diamond, gold, platinum, ferrous and non-ferrous metals, coal, and industrial minerals.

The mining sector uses a vast array of equipment, which accounts for high maintenance costs for most mines in the world. Maintenance accounts for 20 to 50% of the total cost of production. Financial indicators are required to ensure costs are properly managed and controlled (Kotze & Visser, 2012:14).

The mining industry in South Africa performed poorly in the past decades. The contribution of mining to the GDP was halved since 1994. Statistics show that downtime, electricity outages and new regulations and policies had a severe impact on mining production (Reuters, 2019).

For example, year-on-year production dropped by 3.3% in only one month: January 2019 (NS Energy, 2020). If mining costs could be driven down by improved maintenance, it could have a beneficial effect on the whole mining industry that could create many job opportunities in South Africa.

One of the contributing factors in productivity and profit is machinery downtime. Close estimation of actual production time can be achieved by applying Overall Equipment Efficiency (OEE) analysis on a scheduled time approach (CR, 2019).

Factors having an impact on the business are:

- Equipment failures
- Planned and unplanned maintenance
- Idle time
- Waiting time, especially when processes are linked to one another
- Environmental disorders (Fundi Maseko, 2019)

The concept of Cost of Quality (COQ) was first initiated by Joseph Juran in the early 1950s (Glogovac *et al*., 2019:280). He defined COQ as a total cost that will not exist if the quality of a product meets specifications. Horney and Bohan (Glogovac & Filipovic,2018:1522) also defined COQ as all measures taken by the business to ensure quality standards are met consistently. In the past, COQ was only regarded as rework, repair, and warranty costs. Over the years, the models of COQ have been designed to categorise and report COQ.

Feigenbaum developed the Prevention-Appraisal-Failure (PAF) model in 1956. Nowadays, the PAF model is used by many businesses to measure COQ.

The PAF model is grouped into prevention-appraisal-failure

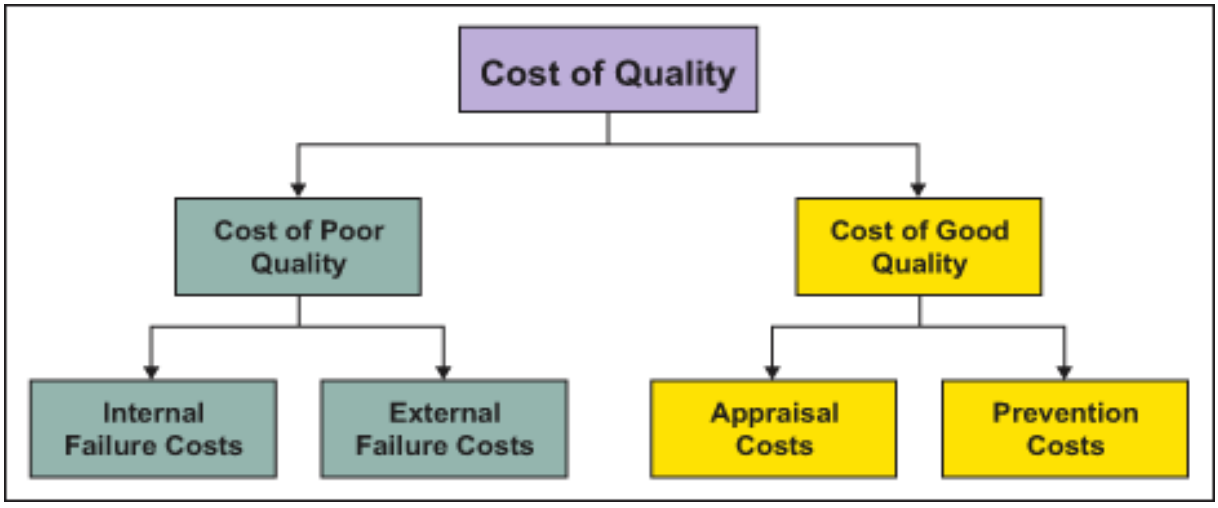


Figure 1: Breakdown of COQ (Kau & Nel, 2019)

Prevention costs are those costs associated with investigating, minimising, and preventing any defect. Appraisal costs are those costs associated with examining the acquirement of quality needs such as costs of confirmation and any control conducted in the quality stage. Internal failure costs are costs arising within the business, such as defects, scrap, rework, re-testing, or redesign. External failure costs are all after-sale costs to a customer, such as non-conformities causing claims to warranties or penalties experienced (Modhiya & Desai, 2016: 87-94).

Customer service has become the focus area for most businesses in the world. Customers often switch to a product or service that is accompanied by the best service in the market. Most businesses are therefore regarding customer service satisfaction as a core focus area of the business (Kursunluoglu, 2011:52). Customer satisfaction is concerned with the following elements:

- Product or service quality
- Relationship
- Financial cost versus benefit
- Overall customer experience

Nowadays, most businesses are aware that customer satisfaction is not just being good to customers, but also pivotal to business success. Interaction with customers is very crucial to the business. Customers are increasingly regarded as the main responsibility of most businesses (Business 2 Community, 2012).

1.4 RESEARCH OBJECTIVES

This study consists of primary and secondary research objectives.

1.4.1 Primary objective

- To investigate which maintenance strategy should be used to maximise the reliability and availability of vertical roller mill technology at the lowest total cost.

Shifting from a traditional reactive to a proactive approach to reduce hidden costs involves a concerted effort. The following keys must be taken into consideration:

- A clear strategy must be defined
- Policies must support the strategy
- Procedures must support the strategy and policies
- The correct tool to support the implementation process

1.4.2 Secondary objectives

- To determine the effect of maintenance on availability through a literature study.
- To quantify vertical roller mill maintenance cost through technical analysis.
- To determine the perceptions of selected vertical roller mill role players on the effects of maintenance on total availability and cost.

1.5 RESEARCH METHODOLOGY

A mixed-method approach was used in this study to meet the research objectives. Questionnaires were distributed to participants and the Vb7 condition monitoring electronic tool was used as a part of analysing collected data from the vertical roller mills.

1.6 POPULATION AND SAMPLING

When conducting a study about an issue, it is very hard to collect data from all individuals in a group. A sample must be selected, and that sample is the group of those individuals who take part in the study (Nkoane, 2018:5). To conclude the study, a sample must be selected that is representative of the whole group.

Sampling methods consist of the following types:

- **Probability sampling:** All people in the group have an equal chance to take part in the study.
- **Non-probability sampling:** Not all people in the group will take part in the study and participants are selected based on other criteria such as knowledge of the topic, availability of the participant or institutional barriers.

Probability sampling methods include simple random, stratified random, multistage and cluster sampling. Non-probability sampling includes convenience, snowball, purposive and focused sampling methods.

It is crucial to decide on which sampling method to follow when conducting research quota sampling (Scribbr, 2020).

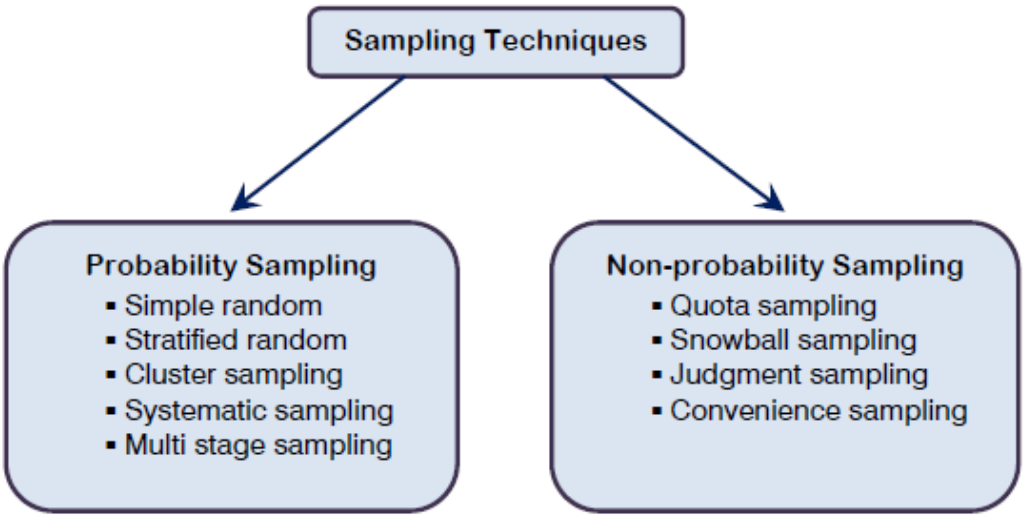


Figure 2: Sampling techniques (Taherdoost, 2016)

1.6.1 Probability sampling

Simple random is where every member of the population has an equal chance of being included in the sample (Taherdoost, 2016:20).

Simple random sampling has the following disadvantages:

- A list of all units in the population is required.
- In certain studies, such as surveys by means of personal interviews, the cost of getting the sample can be high due to a wide geographical footprint.
- There is a possibility of high errors of estimation.

Stratified sampling is where the population is divided into sub-groups and random sampling occurs within each group. Sub-groups can be from organisation size, gender or occupation. This sampling is utilised where there are differences between groups in a population. The objective of stratified sampling is to guarantee that every stratum is adequately represented (Taherdoost, 2016:20).

Cluster sampling is where the population is divided into clusters or groups. It is advantageous for researchers whose subjects are fragmented in a large geographical area because it saves a great deal of time and money. Cluster sampling is done by:

- Choosing a cluster for sampling frames such as the type of organisation or geographical area.
- Numbering each of the clusters and
- Picking a sample in each cluster using random sampling (Taherdoost, 2016:20).

The systematic sampling technique is simple because using systematic sampling, a smaller sample may be selected from the sample (Taherdoost, 2016:20).

Multistage sampling involves a process of moving from a large to a narrow sample, using a step-by-step process (Taherdoost, 2016:20).

1.6.2 Non-probability sampling

Quota sampling is a non-random sampling technique where participants are chosen based on predetermined characteristics in such a way that the sample will have the same set of characteristics (Etikan & Bala, 2017:3).

Snowball sampling is mostly applicable to small populations where access is difficult due to their closed nature. Examples are secret societies or professionals that are not accessible (Etikan & Bala, 2017:3).

In **judgement sampling,** persons are selected to provide crucial information that cannot be easily acquired from other choices. In this case, a researcher includes a case or participants in the sample because they believe that inclusion is guaranteed (Etikan & Bala, 2017:3).

In **convenience sampling,** the participants are available and easily accessible. It is one of the most favoured sampling techniques compared to other techniques. It helps to defeat many limitations associated with research (Etikan & Bala, 20173).

1.6.3 Sampling size

Most researchers prefer to use a small sample, even though a large sample can guarantee satisfactory results. The smaller the population, the larger the size of the sample needs to be relative to the population (Nkoane, 2018:5).

For this research, the total population of people with knowledge of the topic was seven people, and all of them were targeted, with all participants responding.

Convenience sampling was used in this study. The sampling included an element of snowball sampling, where people who are approached for interviews are requested to give names of other people who might be able to offer informed views on the topic. Interviews were stopped when saturation was reached. Saturation is defined as a point where no new information appears during an interview, and after saturation had been achieved, three more interviews were conducted. At the end of the interview stage, an analysis was carried out of whether sufficient people from all departments have been included in the study and, if necessary, more interviews would have been arranged. This did not prove to be necessary. All different races within the organisation were included in this research.

1.7 RESEARCH LIMITATIONS

This study is only focused on participants from Company A and its mother company, Company B. Company B is a mining organisation with various operations in South Africa and Mozambique.

1.8 ASSUMPTIONS

The study took place in a specific timeframe. Production and maintenance costs and availability of material could fluctuate with changing circumstances. The assumption provided an accurate picture that could also be used in other settings and timeframes.

1.9 STRUCTURE OF THE STUDY

Chapter 1: Introduction to the research problem

Chapter 2: Literature review

Chapter 3: Research methodology

Chapter 4: Results and findings

Chapter 5: Conclusions and recommendations

1.10 CONCLUSION

This chapter outlined the structure of the mini dissertation. The problem statement including research objectives were also defined. The next chapter explains the literature review that is used in this study to answer research question and objectives.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

The theory reviewed in this chapter defines and describes the vertical roller mill (VRM) technology in the mining sector, the impact of COVID-19 on the mining sectors in South Africa and worldwide, milling alternatives, business impact and benefits of vertical roller mills, other studies conducted in VRM technology, inventory management, and cost of quality.

2.2 VERTICAL ROLLER MILL TECHNOLOGY

Vertical roller mill (VRM) originated from Japan and was designed by Tower Mill Kobuta Corporation in the 1950s. A vertical roller mill was first used in the mining industry in the 1950s. The type of VRM depicted below is called a tower mill. A tower mill consists of a cylinder, with the screw assisting the movement of grinding. The movement is caused by the motor drive unit situated on top of the cylinder connected to the screw. VRM is preferred in the industry due to its primary grinding application and efficiency, which is higher than that of ball mills (Douglas *et al*.,2014:186).

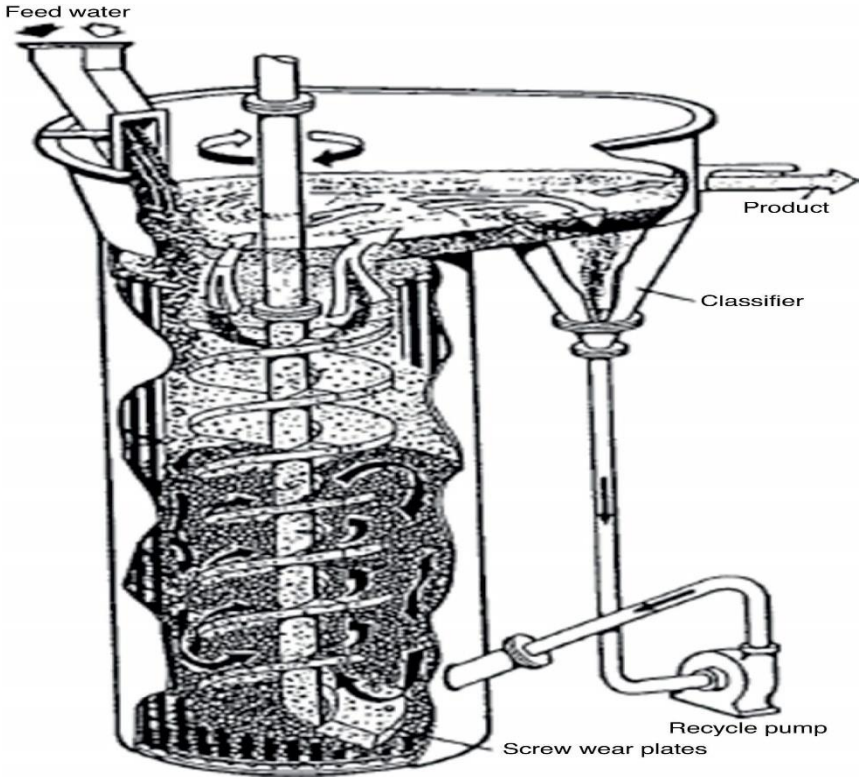


Figure 3: Tower mill (Douglas *et al*., 2014)

2.2.1 Benefits of vertical roller mills

- Vertical mills have high efficiency, are energy-saving and are environmentally friendly. Power consumption is between 20 and 30% better than a ball mill.
- Vertical mills have reduced investment costs, a simple layout and use a small floor area. A ball mill covers 70% of a building, while the vertical roller covers 60%. The dust is collected via baghouse or electrostatic precipitator.
- Tower mills are easy to operate and maintain and the operation is controlled automatically.
- In a tower mill, it is easy to discover whether there is something wrong with the product quality.
- It has limited wear with high utilisation; during the grinding process, there is no direct contact between the metals (Grindplant, 2014).

Cement industries changed to vertical roller mills many years ago to reduce energy consumption, cost and to minimise CO_2 emissions. Vertical roller mills were first introduced in the cement industry in the mid-1990s by Loesche with suitable technology for grinding slag and clinker for cement production.

A vertical mill consists of a grinding table, where particles are blown upwards to the classifier by an air stream – the classifier being part of the mill casing. Particles not meeting the specifications are rejected back to the grinding table for further grinding or milling (Schaeffer, 2001:1155). The vertical roller mill is the grinding mill that, combined with multi-functions such as drying and dissociation, is used for grinding materials like minerals, coal, and petroleum coke. This type of mill is mostly used in blended, slag and Portland cement for grinding (Vijaya & Tayalalitha, 2017:5758).

A vertical roller mill gearbox is heavy-duty, with input driven by a second-motion gear and a bevel gear set. The output shaft is coupled with the grinding table. The ring gear is supported by the thrust bearing at the bottom, which carries the weight of the gearbox

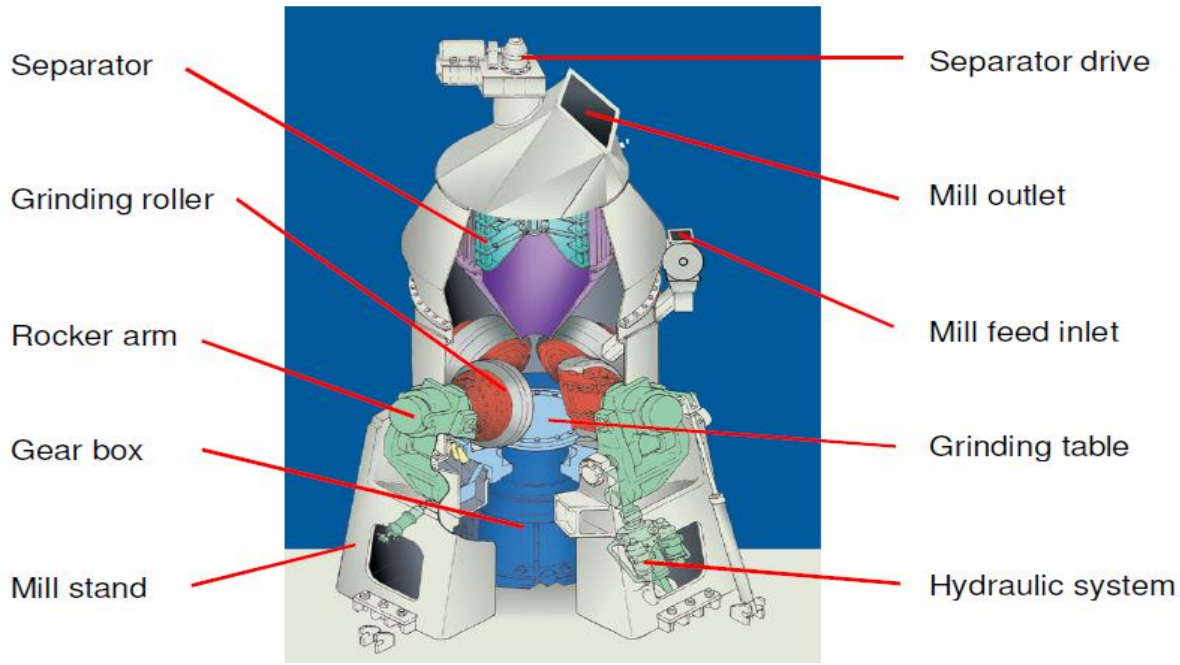


Figure 4: Vertical roller mill (Vijaya & Tayalalitha, 2017)

A bevel planetary gearbox is preferred by most industries due to the following advantages:

- There is a grinding force because the gears are out of the way from the table.
- Strong round gearbox casing
- It is easy to maintain. Stripping and assembling are done quickly without waste of time.
- When in operation, they run quietly due to the high-speed bevel stage being situated deep within the gear section.
- They are very efficient due to the coupling performance of planetary gear (Pawar & Mukhopadhyay 2015: 663)

The left picture below is a bevel helical gearbox and the right one below is the bevel planetary gearbox, both for VRM.

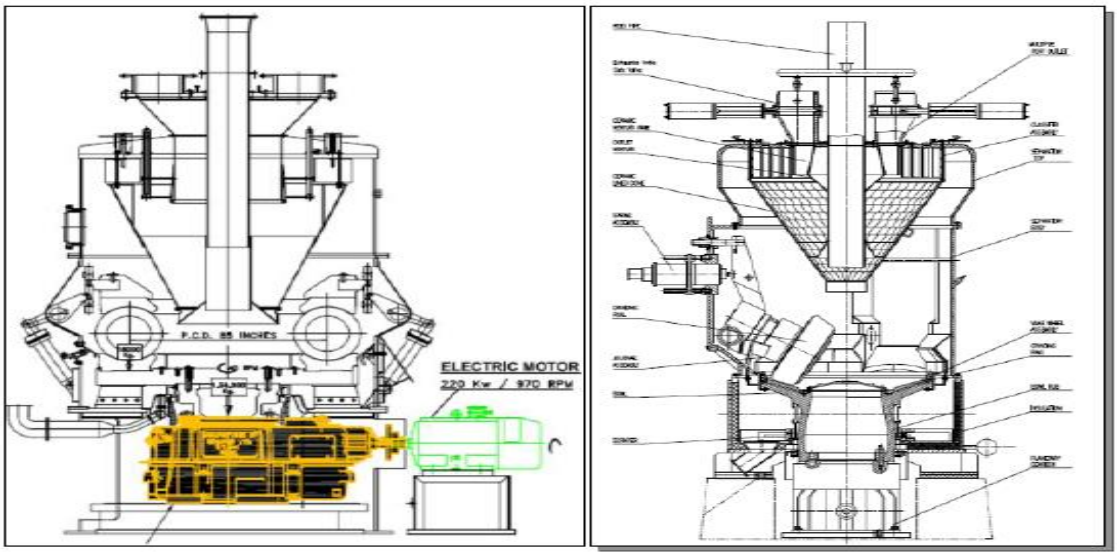


Figure 5: Bevel helical and bevel planetary gearboxes (Pawar & Mukhopadhyay, 2015)

2.3 MINING SECTOR IN SOUTH AFRICA AND WORLDWIDE

2.3.1 Mining sector in South Africa

South African ore reserves' worth is estimated at R20.3 trillion. South African is the fifth largest mining sector globally in terms of GDP. South Africa has the largest reserves of manganese, platinum, gold, diamond, chromite, vanadium, coal and chrome. The figure below shows growth rates in the mining sector (BSA, 2012).

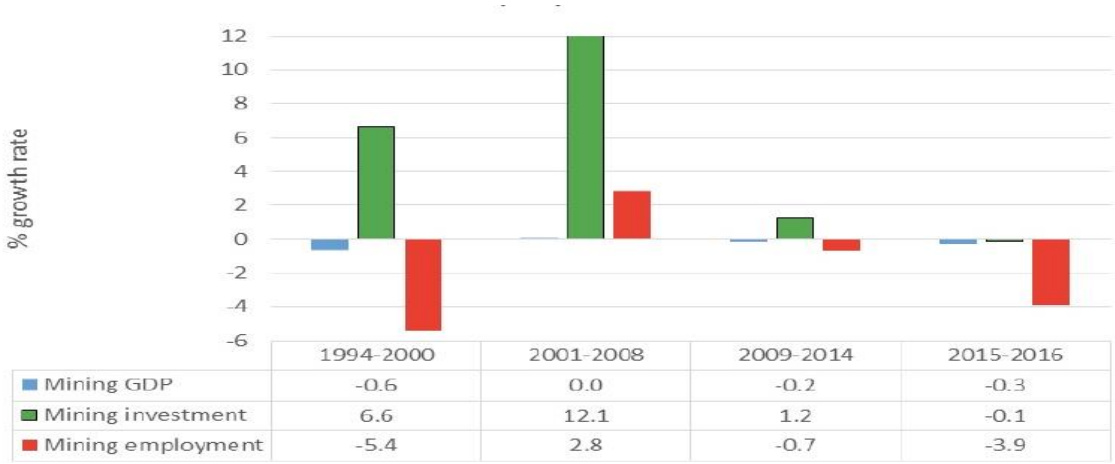


Figure 6: Growth rate in the mining sector (MDC,2017)

The economy of South Africa was historically dependent on the mining sector, especially on gold. This is very important in terms of foreign exchange. Furthermore, in 2009, it was the fourth-largest diamond producer in the world. South Africa also has

reserves of other metals, minerals, energy minerals, non-ferrous metals and minerals, ferrous minerals, and industrial minerals. However, the contribution of mining to the GDP has declined in the past 10 to 20 years (BSA, 2012).

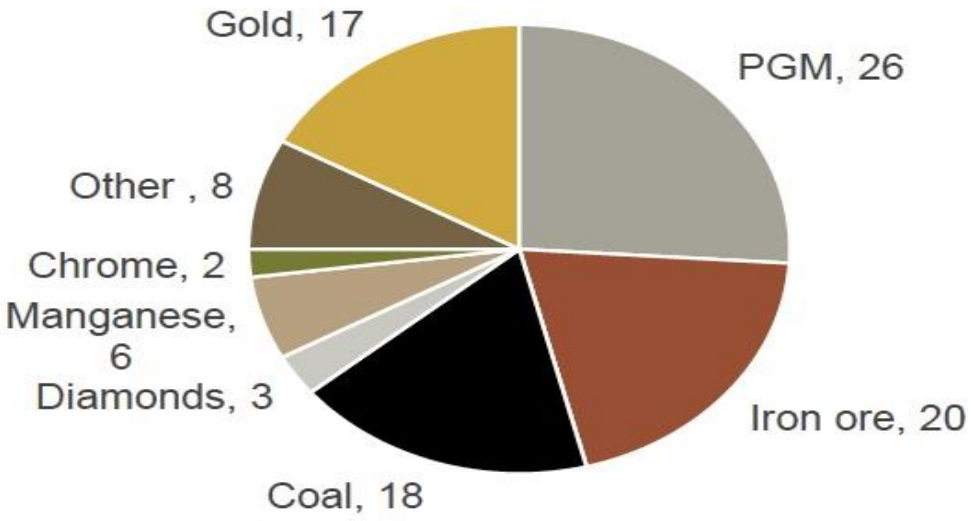


Figure 7: Summary of exports in 2016 (**MDC, 2017)**

The World Health Organisation (WHO) confirmed the COVID-19 outbreak pandemic in early 2020. COVID-19 outbreaks impacted many mining businesses, with worldwide social distancing being required and causing most capital projects to be slowed or put on hold. This pandemic has shaken the mining business worldwide. The nervousness of mining executives on the impact of the pandemic on mining does not seem to abate.

Despite promising results brought about by surging commodity prices and numerous cost-cutting exercises, mining businesses are still under pressure. Restriction protocols in the mining business caused production shutdowns in many mines. For example, Alta Zinc production in northern Italy has shut down its largest project and in Mongolia, Rio Tinto stopped its non-essential operations after the first diagnosis of COVID-19. Currently, Anglo American is demobilising their 10 000 strong construction manpower at their copper project in Peru.

Capital growth in the mining business has been delayed or stopped. Although global capital expenditure of the 20 largest mining businesses grew by 12% in 2019 to achieve $49.1 billion, currently everything has been on hold due to the pandemic (Shabir Ahmed,2020).

South African mining businesses have also been negatively impacted by the spread of COVID-19. Most mining operations are still running at low levels of production. The Minerals Council of South Africa (MCSA) has recently published ten action plans with measures dealing with COVID-19. The lead in implementing these will be taken by the WHO and the National Institute for Communicable Diseases (NICD) (Shabir Ahmed, 2020).

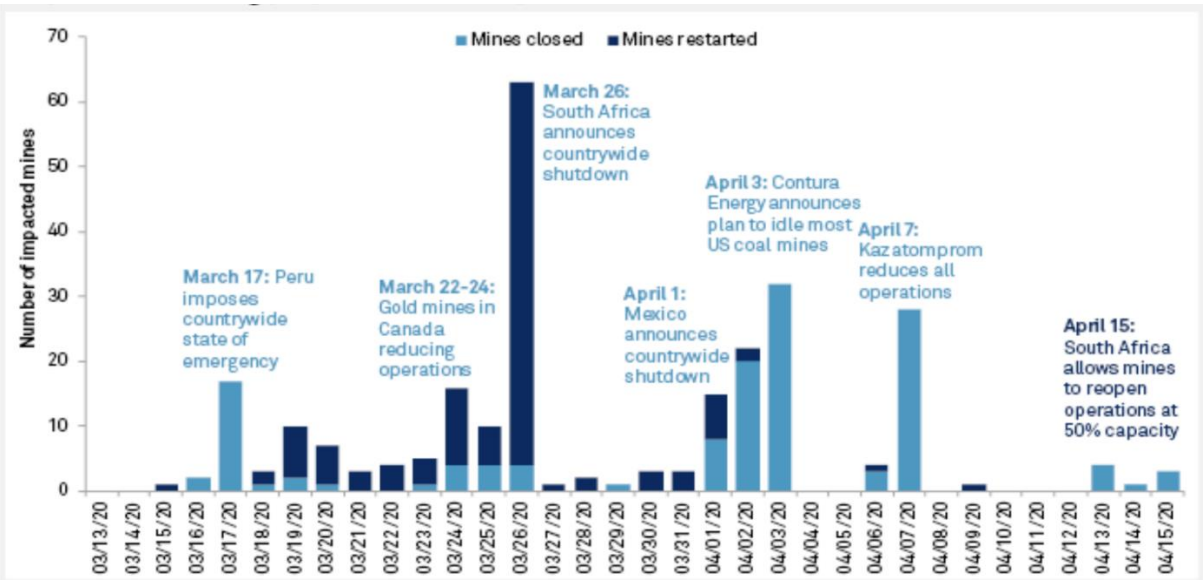


Figure 8: Closure and opening of South African mines during national lockdown (WEF, 2020)

2.3.2 Global mining sector

Most industries worldwide depend on the supply of minerals and metals. Coal is one of the leading global energy resources. The net profit margin of the mining sector dropped from 25 to 10% in 2019. China, Indonesia, and the United States are the largest coal producers worldwide. China is also the largest producer of iron ore, and it has become the world's leading mining country with almost 62% of the world's production in 2019. China is also the world leader in gold production. The leading mining industries are Anglo Australia, BHP, Rio Tinto, and Newmont in the United States (Statista, 2019).

Mining plays a crucial role in the economy of the United States. In 2018, the output amounted to 627 billion US dollars, which was an increase compared to 2017. This sector employs almost 672 000 people (Statista, 2019).

When the COViD-19 pandemic started late in 2019 and early in 2020, the whole world was going through economic hardship of unemployment, which caused a severe reduction in downstream sales of metals and minerals. Most people, especially economists, believe that the world is in a recession (Pwc, 2020). The spread of the coronavirus forced the mining industry to initiate a lockdown to minimise the spread of the virus. The virus closed activities in many industries across the world. Firstly, it was China early in February 2020, and then most of the rest of the world in March 2020. The lockdowns caused the stock market to crash, followed by a recession (Pwc, 2020). The biggest impact of the lockdown on the mining sector was the drop in demand due to reduced industrial production and construction. When mining employees tested positive for the coronavirus, they had to go into quarantine, which negatively affected production (Pwc, 2020).

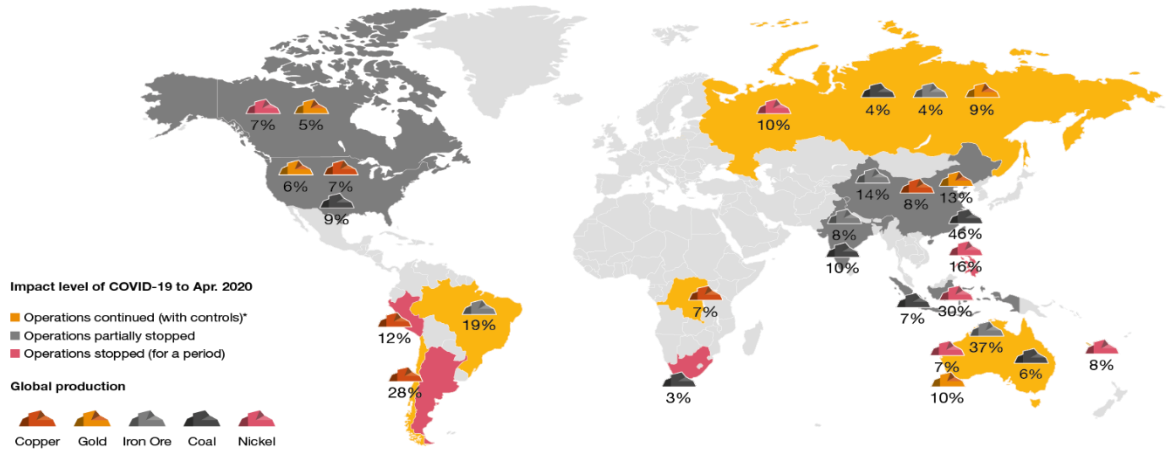


Figure 9: Production overview and Covid-19 on mining operations worldwide (Pwc, 2020)

2.4 MILLING OR GRINDING OF RAW MATERIAL ALTERNATIVES

There are several alternative ways to grind raw materials. The following list is not exhaustive, but lists the major technologies used for grinding.

- Tower mill: The mill was designed in Japan by Kubota. Tower mill is the first low speed stirred mill and was first used in the minerals sector.
- ISAA mill: This was invented in 1990 between Mount Isa Mines Limited and Net ACH. A 1.1 MW motor was designed and installed at Mount Isa Mines for

grinding lead or zinc concentrate. In 1995, five mills were installed at McArthur River Mining.

- Vertical mill: It is like a tower mill. This mill was designed by Svedala. Currently, there are more than 220 vertical mills installed worldwide.
- Sveldala detritor: The mill was developed by ECC International in the 1960s. There are more than 200 mills installed in the world. This mill is used to mill kaolin and calcium carbonate. This type of mill was first installed in Australia at the Elura zinc mine. Century zinc mine also uses this mill.
- Sala agitated mill: This mill was developed by Sala, and it is mostly used in Europe.
- ANI Metrotech SVM mill: This mill was originally developed in South Africa and seven mills have been installed to date (Jankovic, 2003:337)

2.5 BUSINESS IMPACT OF VERTICAL ROLLER MILL IN THE MINING SECTOR

The biggest negative impact of a vertical roller mill on production is when the mill is experiencing downtime. Apart from loss in production, downtime causes a direct cost of late deliveries to customers but could also result in customers suing the mine. Profits can be lost due to substitutions, low quality, or the frequent need for vertical roller mill repairs (Dhayagude, 2014). Indirect costs that the business can face include lost opportunity and loss of loyalty from customers (Dhayagude, 2014).

When the vertical roller mill is stopped due to a breakdown, the mine must still pay idle production employees. Inventory in the warehouse gets depleted in the absence of production. Downtime prevents the business to build up inventory or stock for customers. This can take time to catch up and could result in lost sales. When the business focuses on reactive maintenance, there is no time for innovation (Daisyme, 2018).

2.6 STUDIES CONDUCTED ON VERTICAL ROLLER MILLS

Author/s	**Year of publication**	**Title of the article**	**Background of the article**
Pawar, G.J., Soumendu, J. & Mukhopadhyay	2015	Application of design failure modes and effect	Provides possible corrective action to be

		analysis (DFMEA) to vertical roller mill gearbox	considered in the design of the vertical roller mill.
Shagholi, H., Barani, K. & Yaghobi, M.	2017	Application of perfect mixing model of simulation of vertical roller mills	To discover the breakage distribution function of the material using the compressed bed breakage test.
Nyakunuhwa, H.S.	2019	Effect of VRM on a polymetallic sulfide ore and the floatation response as compared to conventional wet and dry rod milling	To examine the floatation reaction of complex ore milling of VRM as compared to reaction from conventional laboratory scale of wet and dry rolling mill.
Bakker, J.D.	2014	Energy use of fine grinding mineral processing	Investigating grinding technologies and seeking ways to reduce operating costs.
Gerold, G. & Stapelmann, M.	2019	Investigation on floatation behaviour of a copper sulfide ore after dry grinding by Loesche vertical roller mill	To determine the behaviour of wet and dry ore grades' floatation, with the gaol to achieve energy saving.
Bhaskar, B & Jayalalitha, S.	2017	Process control for cement grinding in vertical roller (VRM): A review	The energy consumption saving of 30-40% of vertical roller compared to other grinding technologies.
Fatahi, R. & Barani, K.	2019	Modelling and simulation of vertical roller mill using population balance model	The implementation of population model in a cement clinker circuit using vertical roller mill.
Altun, D., Aydogan, N.A. Altun, O. & Benzer, A.H.	2017	Performance evaluation of vertical roller mill in cement grinding: Case study of ESCH cement plant	To determine estimates of mass flow rate and distribution size of each stream by means of mass balance.

2.7 MAINTENANCE MANAGEMENT

There are two options in performing maintenance procedures. The first option is reactive maintenance, where the user only maintains the equipment or system when it fails. This maintenance procedure restores the system's functionality. The second option is proactive maintenance. This is where all maintenance tasks are scheduled on intervals recommended by the original equipment manufacturer (OEM) or by the equipment or system history. These intervals are often prescribed by the occupational safety laws of a country (Bellstedt, 2019).

The main objective of plant maintenance is to increase availability, reliability, and product quality to reduce operating costs. Because maintenance activities are costly, deciding on a maintenance strategy is a crucial step in optimising costs. Senior management looks at the costs before they decide on which maintenance strategy to follow. The overall objective of maintenance is to ensure availability of production machinery at the lowest cost (Vishu & Regikumar, 2016:1080).

The importance of maintenance on total output and profit is often under-estimated. The iceberg model below demonstrates the impact of hidden maintenance costs.

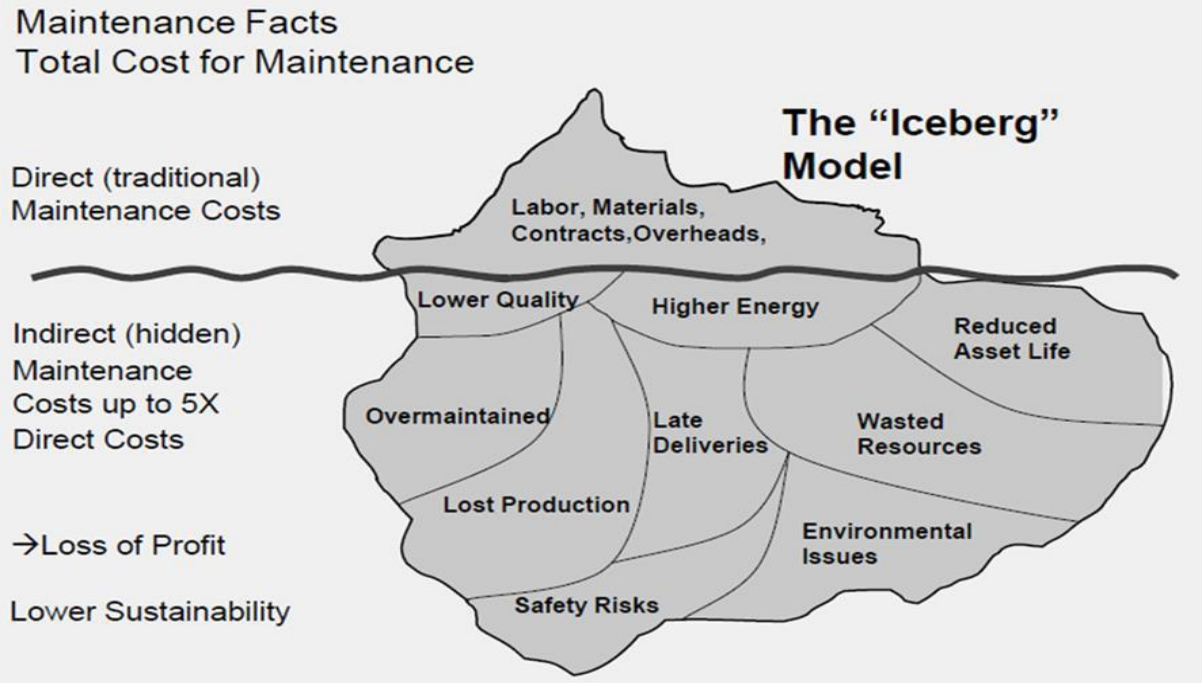


Figure 10: Iceberg model: Total costs of maintenance (Wienker *et al.*, 2016)

To address these hidden costs, certain maintenance concepts have been developed. One of them is reliability-centred maintenance (RCM). RCM has been successfully

applied in many industries to minimise unnecessary loss of production due to equipment failure and to implement efficient maintenance plans. The mining industry also uses RCM to analyse equipment failures and to choose the best corrective action to minimise downtime (Chopra *et al*., 2014:175).

Shifting from a traditional reactive to a proactive approach to reduce hidden costs involves a concerted effort. The following keys must be taken into consideration:

- A clear strategy must be defined.
- Polices must support the strategy.
- Procedures must support the strategy and policies.
- The correct tool to support the implementation process.

These business procedures must include several checks and balances (Weinker *et al*., 2016:414).

Most organisations are facing challenges in improving the availability of the system. Availability consists of two components, which are MTBF (mean time between failures) and MTTR (mean time to repair). The availability of any piece of equipment is then calculated by the formula:

$$\textbf{\textit{Availability = MTBF / (MTBF + MTTR)}}$$

Reliability is measured by the MTBF of the system (Gupta & Kaur,2016:57). MTBF, measured in time units, is the inverse of failure, which is given by the formula below.

$$MTBF = \frac{1}{Failure\ Rate\ (\lambda)}$$

The failure rate, measured in frequency units, is regarded as the state where the system is not meeting its objective or transition from state to non-functional state as the result of the deficiency of any component of the system.

The bathtub curve, described by Junhai and Li (2014:3), shows the optimal operation of a piece of equipment over its lifespan. As per the figure below, the bathtub curve consists of three periods, namely:

- Infant mortality, where failures start at a very high rate, but faults are identified before settling down over time. This usually happens early in the life of the equipment.
- Random failures: faults occur at a constant rate.
- Wear-out failures; failure rates escalate as the life of the product or component increases (Junhai & Li, 2014:3).

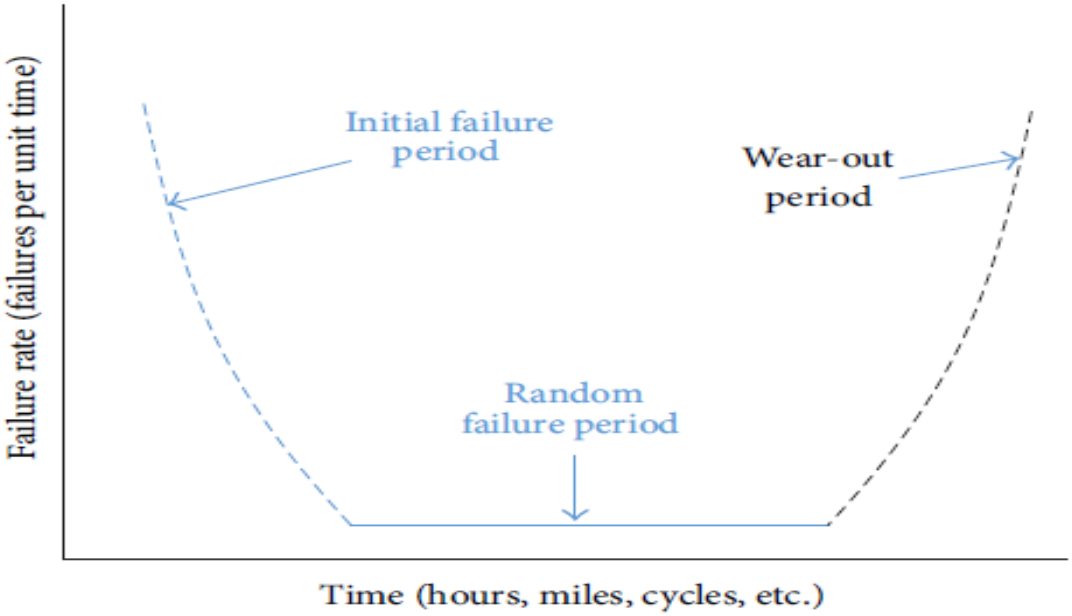


Figure 11: Bathtub curve (Junhai & Li, 2014)

2.7.1 RCM (Reliability-Centred Maintenance)

RCM was developed in air transportation between the 1960s and 1970s by Stanley Nowlan and Howard Heap (Vishnu & Regikumar, 2016:1082.

The procedure for implementing RCM is explained in the figure below. These steps act as a guide to organisations to implement an RCM programme for systems and equipment (Vishnu & Regikumar, 2016:1082).

John Moubray, one of the RCM gurus, defines RCM as a process used to establish what actions must be taken to any piece of equipment to perform its intended function within its operating context.

Routine maintenance is very important to maintain the equipment's intended operation, to ensure the availability of the equipment and to avoid unnecessary downtime (Listani & Sukari, 2019:2).

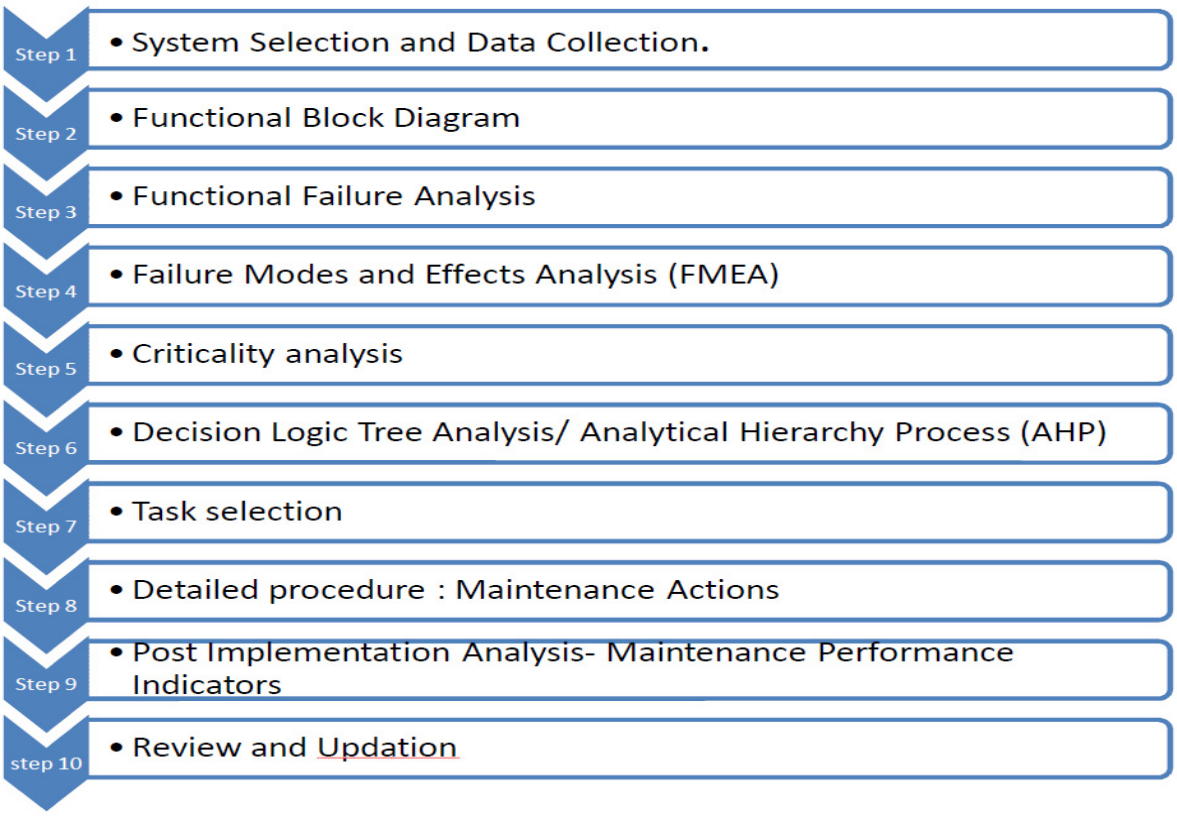


Figure 12: RCM process (Vishnu & Regikumar, 2016)

RCM is based on the following three questions:

- How does failure take place?
- What are the outcomes for safety and operability?
- What can a good maintenance strategy bring to the organisation?

RCM is regarded as a corporate-level maintenance strategy that is designed to optimise the maintenance programme for the business. Reliability and availability are achieved by reducing the probability of system failure (Kullawong & Butdee, 2015:87).

RCM is a super-strategy that includes all the other maintenance strategies that are shown in the figure below.

RCM is defined as a tool that identifies productive and effective preventative maintenance chores for a piece of equipment with specific standard working instructions, for setting up intervals between maintenance chores (Force & Mpisha, 2010:210).

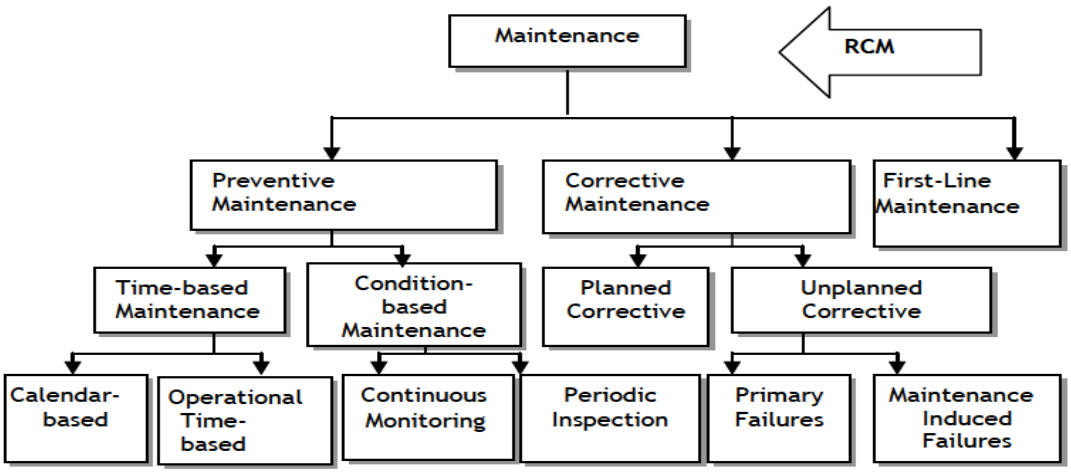


Figure 13: Maintenance strategies (Force & Mpisha, 2010)

The principle and characteristics of RCM consist of the following:

- Functions to maintain,
- Functions to recognise failure modes that might conquer,
- Functions that prioritise based on failure modes.
- Where RCM is correctly implemented, the amount of routine maintenance chores is reduced to minimal (Hamed *et al*, 2016:88).

RCM consists of the following methods:

- To minimise equipment failures.
- To focus on critical equipment criticality and eliminating unnecessary maintenance tasks.
- To maximise maintenance activities that refer to equipment history failures (Hamed *et al.*, 2016:88).

2.7.1.1 Advantages of RCM

- It is regarded as the most productive maintenance programme.
- It reduces maintenance costs by eliminating machinery overhauls.
- It reduces the rate of machinery downtime.
- It minimises equipment catastrophic failure.
- It maximises the reliability of the component/s.
- It involves the root Cause Failure Analysis (RCFA).
- Its attention is more on maintaining critical parts of the machinery (Force & Mpisha, 2010:210).

2.7.1.2 Disadvantage of RCM

- Implementing it can be more costly as it involves training employees and machinery requirements. High costs during implementation have led many organisations' top management to withdraw from this process, and these can lead to the unsuccessful implementation of RCM.
- Savings are not seen by management as they expect quick savings in a short period (Force & Mpisha, 2010:210).

FMECA (Failure Mode Effects and Criticality analysis) is another tool used in many industries to improve the availability of the equipment (Nabdi & Herrou, 2016:47). FMECA is commonly used in product design to identify, define, and banish possible failures of the system or product. Failures are distinguished by a component of severity called FMEA (Failure Mode Effect Analysis).

FMECA consists of critical analysis. FMECA consists of the following types:

- FMECA product: The objective is zero deficiency.
- FMECA process: The objective is zero nonconformity.
- FMECA machine: The objective is zero failures or machine stoppages (Nabdi & Herrou, 2016:47).

FMECA was first used by the National Aeronautics and Space Administration (NASA) to improve and verify the reliability of a hardware space programme called MIL-STD-785.

FMECA is used to identify and analyse the following:

- The potential failure of all different parts of the system.
- System effect failure, on how to eliminate the system failure.

FMECA includes the following steps (Bambang *et al*., 2019:2863):

- Identification of failure including all causes.
- Examination of the impact of each failure mode of the system.
- Identification of methods to detect failure.
- Identification of all corrective measures to correct the failure (Bambang *et al.*, 2019:2863).

Adhikari *et al*. (2014: 602) mention the following basic steps of FMECA:

- Interpreting the system including the identification of internal functions and interfaces, the anticipated performance in different levels of complexity, limitations, and definition of a system failure.
- Performance of functional analysis, demonstrating operation linkage and dependency of functional entities.
- Identification of failure modes and effects, all potential failure modes within the system.
- Establishing the severity ratings of failure mode.
- Establishing the occurrence of the frequency of failure mode and failure mode analysis.
- Spotting established to rate from control design criteria.
- Risk priority number (RPN), which represents severity (S) X occurrence (O)

2.7.2 Predictive maintenance

The objective of predictive maintenance is simply to warrant proactive scheduling of remedial work and to prevent unexpected equipment downtime. Accurate equipment performance results can only be obtained while the equipment is running. This can be achieved by connecting sensors to the equipment to record different readings like temperature and control voltage (Sipos *et al*., 2014).

The figure below demonstrates the workflow of predictive maintenance. The central database is the key to a predictive maintenance platform. The analysis consists of the following steps:

- Preparation of data
- Building of the model
- Evaluation of the model
- Monitoring

To construct a model for a target part, the analytic module extracts appropriate data from the central database (Sipos *et al*., 2014).

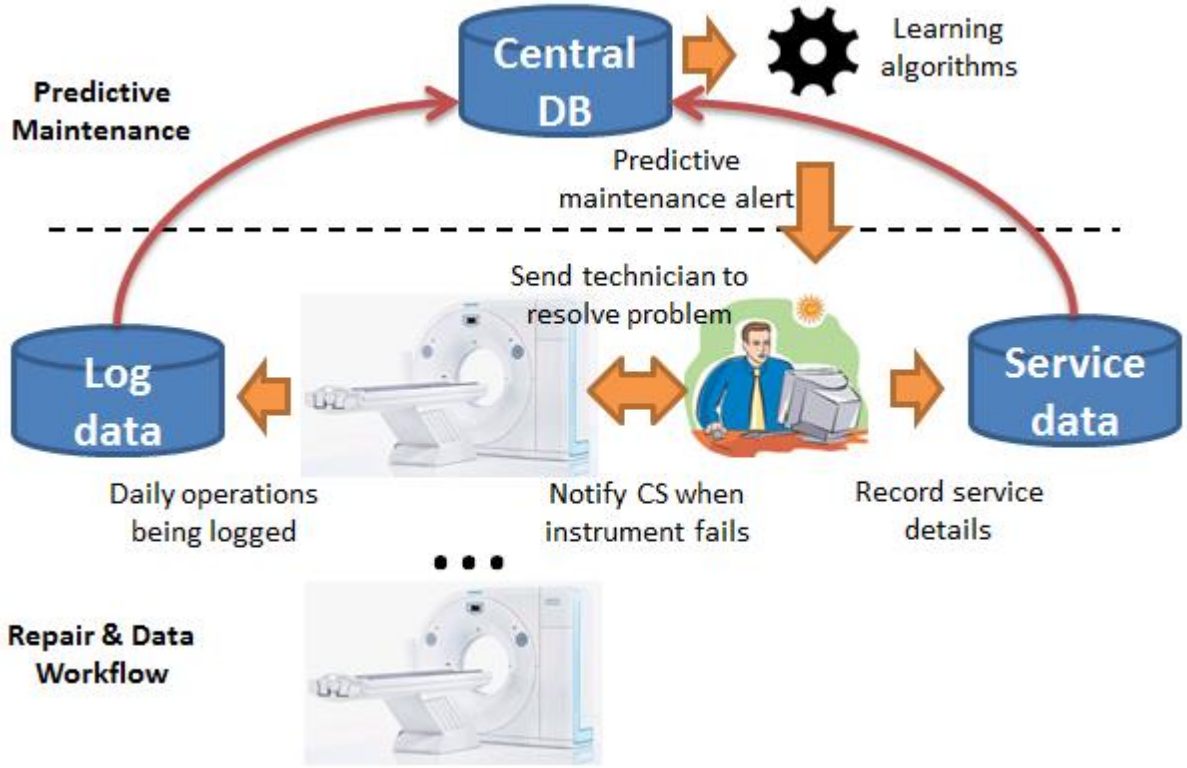


Figure 14: Predictive maintenance process (Sipos *et al.*, 2014)

2.7.2.1 Predictive maintenance features

Predictive maintenance consists of four maintenance features, namely scientific, estimation, timeless and condition monitoring.

- Scientific: In predictive maintenance, the monitoring of the equipment is done manually or through online monitoring. The information regarding the equipment's performance is extracted by experienced personnel, and this information is used to analyse the performance of the equipment. The results will determine whether the equipment needs to be maintained or not so that the user can decide to repair the defect on the equipment.
- Estimation: The equipment's performance is predicted for future operating trends. In this regard, factors such as the exactness and changes that will affect the expected results are used to predict the operational performance of the equipment. The team conducting predictive maintenance must be trained and have the necessary skills to diagnose possible failures of the equipment.

- Timeliness: In predictive maintenance, current data is used to monitor the condition of the equipment using full accurate data. A full diagnosis of the equipment is done, also including spare parts inventory to improve accuracy. Predictive maintenance guides users to select the correct time to repair the equipment, and how much will be spent on spare parts required.
- Condition: Condition monitoring is fundamental to predictive maintenance's fault diagnosis technology. Condition monitoring can occur online or offline. Offline monitoring is appropriate, practical, quicker, and intuitive, and is commonly used for routine inspections. Online technology is error-free, timely and data can be easily stored (Wang *et al*., 2016:296).

Fault diagnosis: Fault diagnosis determines the repair mode. It is identified while the equipment is running and the status monitoring information recognises different parameters and the equipment's status by analysing data through processing and extracting technology (Wang *et al*., 2016:296)

Predictive maintenance consists of a system with the necessary technology to do the following:

- Condition monitoring
- Fault diagnosis
- Define prediction

Predictive maintenance consists of the following strategies:

- Identification of parameters
- Observation and monitoring
- Maintenance work orders
- Project maintenance owner (Wang *et al*., 2016:296)

Predictive or condition-based maintenance decides how the system must be maintained, and whether the system must be maintained in its current state. Experts are encouraged not to give up on basic methods of maintenance, but rather to follow the latest routine maintenance technologies (Alaziz & Al-Zenki, 2014:165).

Figure 15: General predictive model of replacement based on a dynamic programme (Alaziz & Al-Zenki, 2014)

2.7.2.2 Condition monitoring

Another maintenance strategy that is like predictive maintenance is condition-based maintenance. In this maintenance strategy, alarms are activated giving the user an alert before a breakdown will happen (Sakib & Wuest, 2018:268). Condition-based maintenance was first introduced in 1975. This maintenance strategy suggests that maintenance action is taken to restore the equipment based on the information obtained from the monitoring process. The picture above shows the process of condition-based maintenance (Ahmad & Kamaruddin, 2012:136).

Condition Monitoring (CM) is the process of obtaining the status of the machinery and predicting the capability of the system at any given stage. Prediction and diagnosis based on CM give a better indication of plant maintenance tasks. Condition-based maintenance using machinery condition assessment has several advantages compared to time-based or reactive maintenance, mainly in terms of minimal downtime and maintenance costs. Vibration analysis, one of the condition monitoring methodologies, started in the 1950s (Hodge *et al*., 2014:1089).

The lifecycle of a condition monitoring maintenance strategy has the following basic phases.

- Maintenance and ideas for expanding the case of condition monitoring utilisation.

- Commissioning to assign monitoring application.
- Engineering to configure the elements of a system.
- The setting of the human interface for plant operation (Hodge *et al*., 2014:1089).

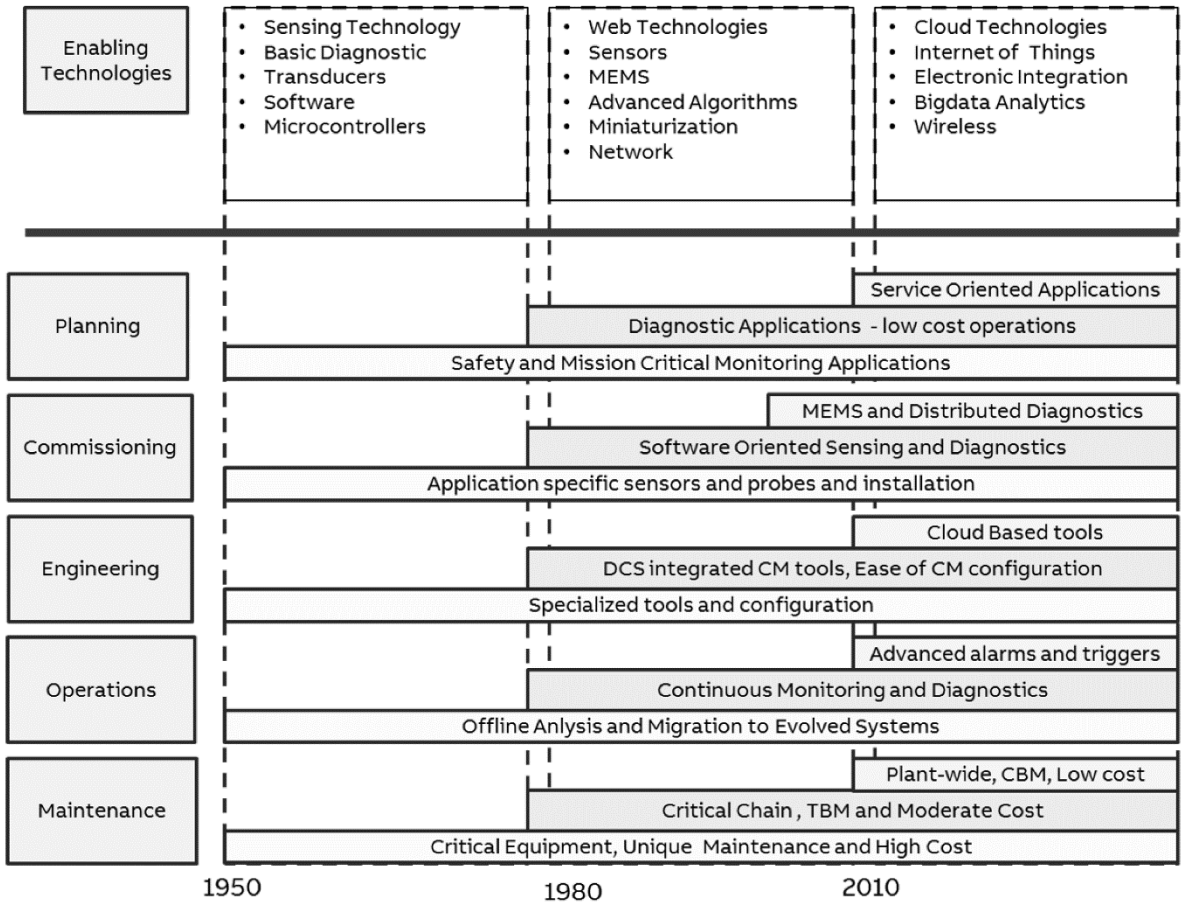


Figure 16: Technology trends of plant monitoring system (Hodge *et al*., 2014)

2.7.3 Corrective maintenance

Corrective maintenance is one of the maintenance strategies where maintenance is only carried out when a piece of machinery is breaking down. Some industries prefer corrective maintenance to breakdown or reactive maintenance. Industries, where corrective maintenance is performed, are mostly where there is no maintenance department or where people are ignorant or hesitant to carry out maintenance activities on the equipment. It is a firefighting maintenance strategy where the equipment is run to failure. Repairing broken machinery has been a traditional method for many organisations (Pasipatorwa, 2020:11).

Most organisations adopting this maintenance strategy are forced to keep enough spare parts and manpower ready to replace a defective or broken component on the

equipment. A good example of reactive maintenance is the replacement of a light bulb (Pasipatorwa, 2020:11).

The advantages and disadvantages of corrective maintenance are as follows:

2.7.3.1 Advantages of corrective maintenance

- If nothing breaks down, maintenance often does not take place at all.
- No maintenance system costs such as condition monitoring and planning costs.
- Less maintenance labour is needed.

2.7.3.2 Disadvantages of corrective maintenance

- There is a high risk of damaging equipment in the long run.
- Loss of production and customers.
- High maintenance costs in spare parts including labour (overtime).
- Less utilisation of resources (Pasipatorwa, 2020:12).

2.7.4 Preventive maintenance

Preventive maintenance is one of the maintenance strategies that involves the repair and replacement of the equipment before the equipment fails. The objective of preventive maintenance is to reduce cost and minimise equipment failure. It also improves productivity and the quality of the product. Preventive maintenance is conducted at intervals recommended by the manufacturer or at intervals recommended by the user, based on the environment where the equipment operates (Ahmad *et al*., 2011:22).

There are different modes of preventive maintenance (Reliableplant, 2019):

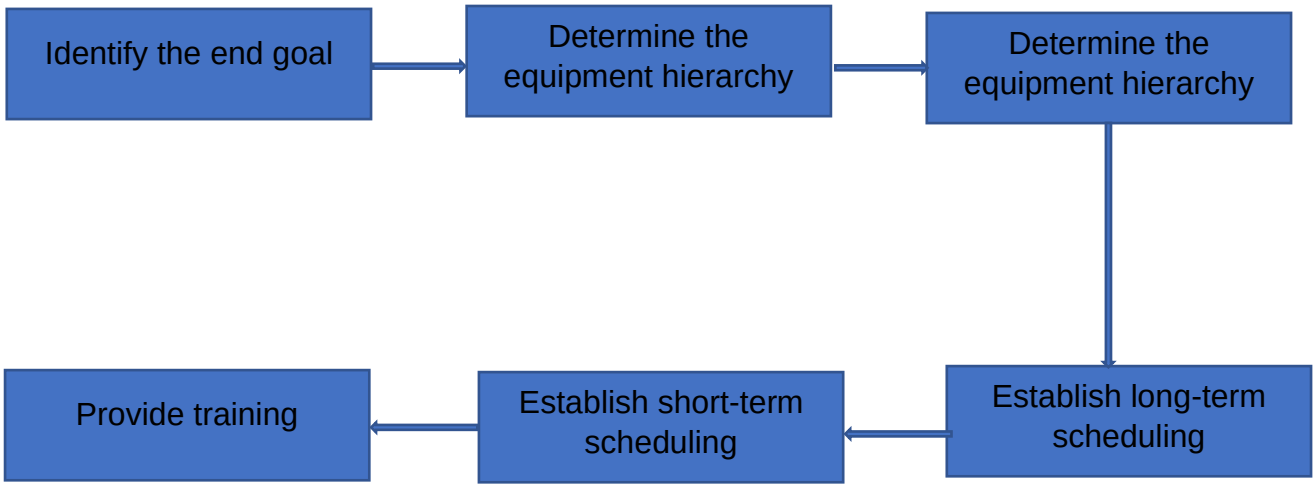
- Calendar-based maintenance: Maintenance is scheduled at specific intervals following the specifications of the OEM.
- Usage-based maintenance: Maintenance is scheduled, based on the hours that the equipment operates. Most businesses maintain their equipment during festive holidays because many suppliers and customers are closed.

Prescriptive maintenance is the same as predictive maintenance. It works hand in hand with software such as machine learning, artificial intelligence, and the internet of things. Artificial intelligence and the internet of things assist with maintenance

scheduling, while machine learning assists with detecting abnormalities during operation. The other objective of preventive maintenance is to delay equipment failure (Reliableplant, 2019).

Condition monitoring is the success of a preventive maintenance programme, when condition monitoring is implemented successfully, the preventive maintenance programme flows very smoothly.

The diagram below guides users on how to design a maintenance plan (Reliableplant, 2019).



2.7.5 Computerised maintenance management system (CMMS)

A CMMS is one of the best Enterprise Resource Planning (ERP) systems used by many organisations across the world for maintenance planning. Between 25 and 40% of CMMS implementation is successful. Most users that use CMMS use only 6 to 15% of the system's capacity (Wienker *et al.*, 2016:415).

Most organisations fail in the implementation of a CMMS because the organisation itself is not readily supported by a computer system. For successful implementation, the organisation must move from a reactive to proactive maintenance approach (Wienker *et al.*, 2016:415).

A CMMS has the following functions and applications:

- It manages assets by recording the history of equipment repairs and spare part lists.

- It manages work orders for maintenance technicians.
- It supports maintenance planning and scheduling activities.
- It controls inventory by giving access to the availability of spare parts.
- It provides a report of performance indicators.

The above-mentioned functions give better efficiency and effectiveness of maintenance activities (Lopes *et al*., 2016:269).

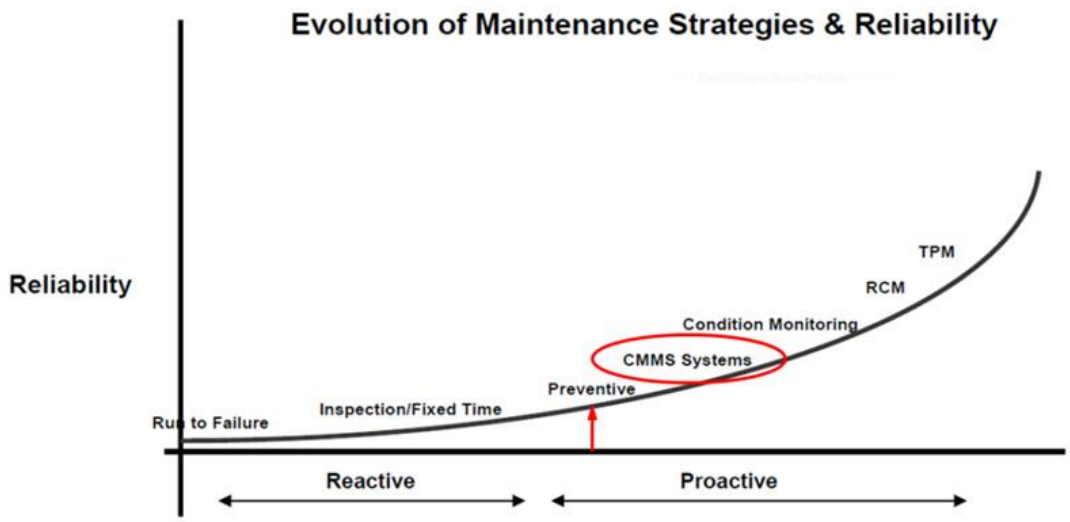


Figure 17: Evolution of maintenance strategy (Wienkel *et al.*, 2016)

2.8 Inventory management in the mining sector

The main aim of inventory management is to improve service to the customer. Furthermore, inventory maximises production efficiency. Inventory management creates effective use of inventory (Lwiki *et al*., 2013:77).

Most businesses are still using inventory management just to minimise costs. However, the objective of inventory management is to keep enough inventory to meet customers' demands and to determine which items must be kept in stores (Plinere & Borisov, 2015:91).

Inventory is part of the business assets, and it plays an important role in the business's operation. Inventory management includes management of the supply of goods from manufacturers to the business' warehouse, and up to the point of sale. An accurate record of products sold, received, or returned must be maintained. Poor control of inventory can have a severe impact on a business.

The following inventory-related factors can have a huge impact on the business (VB, 2017):

- **Unstable inventory:** If inventory is not well managed, it becomes difficult for the business to maintain a balanced level of items. Overstock, understock, and defective stock can easily create a variance.
- **Late delivery of goods** can create incorrect stock information, which makes it difficult for the business to know how many goods are in stock and how many need to be purchased.
- **High costs:** Overstocking is expensive and can have a huge impact on business profit. Old stock that is no longer in use must be sold by the business to avoid costs of high stock sitting on the shelves.
- **Poor customer satisfaction:** On-time delivery and product or service quality play an important role in customer satisfaction. The customer easily loses faith and trust in late deliveries, and that leads them to search for alternatives.
- **Misspent time:** More time is wasted where employees could have completed well-balanced inventory (Katarzyna, 2014:37).

Spare part availability leads to customer satisfaction and ensures that the organisation stays competitive. If an organisation is facing the problem of holding too many spare parts for a long period, this affects Days Working Capital (DWC) in the end-of-year financials (Katarzyna, 2014:37).

2.8.1 Spare parts allocation

When planning for spare parts, the following can be distinguished:

- Maintenance spares are spares required for machine breakdown. These spare parts belong to common products.
- Spare part buffer stock is kept in stock in case of unexpected machine downtime. Such parts are available at short notice and usually, the price is high. This creates a problem for most organisations as they do not want slow-moving parts on the shelf.
- Capital spare parts are normally bought when the new equipment is purchased. Their strategy is different from the buffer stock strategy (Katarzyna, 2014:39).

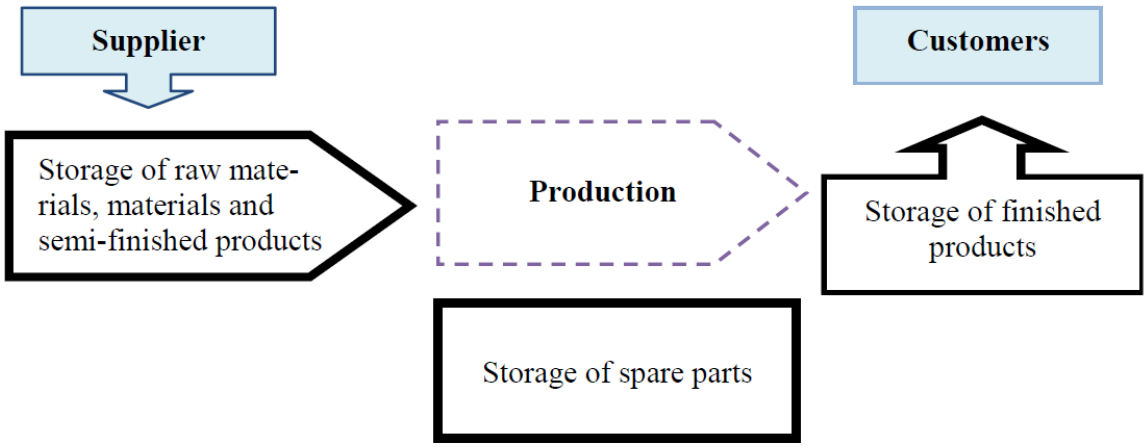


Figure 18: Process of product formation in the organisation (Katarzyna, 2014)

Spare parts can also be classified according to their availability (Katarzyna, 2014:39), namely:

- Key parts, where a purchase order is made before delivery. Planning should be done in time in the case of maintenance shutdown because chances are that spare parts will not be available when needed.
- Industrial parts, of which the need depends on the type of process. The drawings must be available for manufacturing or machining purposes from the end-user.
- Commercial parts are most common for all industries, and they are bulbs, screws, bolts, nuts, filters, and gaskets that are easily accessible, and their lead time is very short.

The spare parts are crucial for every business to ensure the smooth operation of the critical equipment. In the mining industry, critical spares are kept to reduce the financial and commercial cost of downtime. In the mining industry, equipment downtime can be very costly, while holding spares can also be very costly. Determining the balance between the availability of spare parts can be very challenging (Turrini & Meissner: 2019:118).

2.9 COST OF QUALITY

Businesses are under pressure to estimate, scrutinise and recognise to ensure that products or services not only meet the necessary level of quality, but also meet customer satisfaction. Cost of quality is a tool used by many businesses to measure

the performance of the business to prioritise quality improvement within the business. Quality costs can be defined as all costs experienced during the design, execution, operation and maintenance of quality systems, resources agreed for continuous improvement, as well as products not meeting specifications to achieve product or service quality.

Calculating costs of the quality programme have certain advantages in a business (Kau & Nel,2019:1):

- It helps the business to give investment reasons in prevention chores, which assists the business to reduce quality costs to give reasons for quality improvements effort to investment.
- It expands advanced measures for satisfying customer needs.
- Return on investment (ROI) and sales figures will be better and costs will be minimised.
- COQ assists in examining capital investment.
- Phillip Crosby emphasised that quality costs have a huge indirect impact on the overall financial goals of a business. To be certain that the products meet the customer's specifications, the business needs to measure COQ and adjust procedures where necessary. Joseph Juran gave a demonstration of how quality programmes can be used to maximise the quality of products or services. The graph below shows the optimum model of COQ developed by Juran. In the graph below, the minimal level of total COQ can prevail where the quality of conformance is 100%. This tool is more useful for senior management to see if the business achieved its goal in quality improvement and minimising costs (Neyestani, 2017).

It is also believed that reducing non-conformance costs is proof that the business has a relevant quality system to produce products or services with the required level of quality.

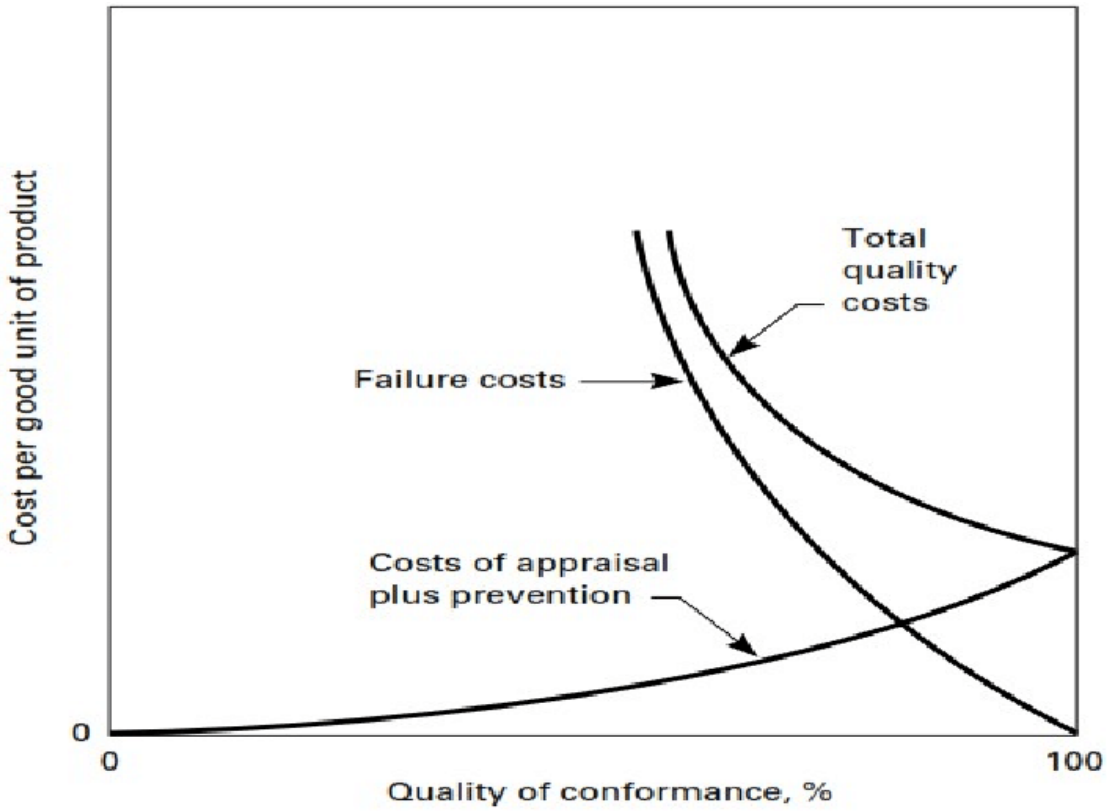


Figure 19: Model for optimum quality costs (Neyestani, 2017)

Armand Feigenbaum mentioned that appraisal costs are those costs related to maintaining quality levels in the business which reveals the conditions and levels of quality management of the business. He further mentioned that appraisal activities are most frequently found in businesses where non-conformance is high, and they exist because the system generates many delusions. Non-conformance causing unnecessary costs can be avoided by introducing prevention activities, which are important characteristics of quality management. COQ is a successful tool for businesses to specify and guide quality management programmes like total quality management (TQM). The biggest costs in the business normally arise from internal failure areas like rework, scrap, re-designing, redoing and so forth (Neyestani, 2017).

2.9.1 Total quality management

TQM was first witnessed in the early 1980s when Hewlett found faults in US manufacturers' quality of products when compared to their competitors, the Japanese. TQM is also referred to as a measure of customer requirements and continuous improvement of quality, which makes it the responsibility of all employees (Khanam *et al*., 2013: 2434).

Total quality entails the execution of TQM. TQM is utilised in business operations to produce products of high quality. Nowadays, quality is critical to the survival of most businesses in a globally competitive environment. Customer satisfaction is the focus of every business; it is regarded as the key dimension to determine the quality of service given by the business (Topalovic, 2015).

For the business to attain success, TQM techniques must be implemented. The International Organisation for Standard (ISO) defines TQM as an approach for businesses management that focuses on the quality and activities of all employees to achieve long-term plans through customer satisfaction. Total quality is also seen as the way businesses guarantee customer satisfaction at all levels.

TQM consists of the following elements (Topalovic, 2015).

- Quality
- Customer focus
- Frequently maximising customer satisfaction
- Continual minimising of real costs
- Structured approach
- Employee's participation
- Incorporation of supply chain and customer chain
- Process improvement
- Benchmarking
- Measurements

A business must understand the customer’s requirements by training the workforce to develop special skills. Customer satisfaction plays the utmost role when implementing TQM. Most businesses implement a quality system to comply with ISO 9000 standards. Most businesses prove and reveal that their service or products are under the requirements of ISO to increase customer satisfaction by implementing continuous improvement systems to achieve certain requirements for Quality Management System (QMS) (Topalovic, 2015).

Customer service is the mainstream for most businesses worldwide. Customers often switch to a product or service that offers the best in the market. Most businesses are putting customer service satisfaction as a core function. Customer satisfaction can be divided into the following classification:

- Product or service quality
- Relationship
- Financial cost versus benefit
- Overall customer experience

Nowadays, most businesses are aware that customer satisfaction is not just being good to customers, but pivotal to business success. Interaction with customers is very crucial to the business. Customers are now becoming the first responsibility of most businesses (B2C, 2012)

2.10 CONCLUSION

Chapter 2 explored the literature relevant to various maintenance strategies used by most industries worldwide, cost of quality and spare part management. The importance of customer services was also outlined. The literature review in this chapter will play a major role in answering the research question.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 INTRODUCTION

The focus of this chapter is on the research methodology used to answer the research question. The technique that is used for sampling, including the instruments used, is also part of this chapter. Ethical consideration is also taken into consideration to warrant confidentiality and privacy given by the participants.

3.2 RESEARCH DESIGN

Research design is defined as a technique a researcher chooses and applies in the research to answer research questions. Research design gives a researcher a chance to decide on the correct research methodology that is suitable to set up research (Jovancic, 2020).

Quantitative research includes systematic and actual investigation through statistics and mathematical numbers and the processing of numerical data. In quantitative research methodology, data is selected and scrutinised. Quantitative research statistics form an important part of mathematics, and it is mostly used to scrutinise and process huge volumes of quantitative data to prove hypotheses. There is the unpredictability that relates to theories under deliberation. Research can successfully be done with questionnaires containing questions and short answers, data acquired can be quantified and estimated.

In this type of research methodology, data is processed using distinctive statical software. Quantitative research methodology has certain advantages, namely:

- Numerical results are not influenced by personal feelings or judgement by considering and presenting facts.
- Simplification of processing huge data.
- Authorise the development of quantitative evaluation measures.

Quantitative research methodology has certain objectives such as an association of practical experiments, the exploration of phenomena, utilisation of advanced statistical tools and questionnaires (Basias & Pollalis, 2017:92)

The quantitative research methodology consists of the following types:

- A survey makes use of a sampling method employing questionnaires to measure a certain group of people's characteristics using a statistical method.
- Correctional; it determines to what extent the relationship exists between more than one group of a population or a sample.
- Experimental; it explores the treatment of involvement into the group of study and measures the results of the treatment.
- Casual comparative is where the problem is investigated by studying variables retrospectively (Apuke, 2017:43).

Qualitative research is the type of research methodology that analyses experiences, and behaviours, including relations by using statistics and mathematics and the process of numerical data. This methodology answers research questions such as what, how, where, and when, and everything is based on the research approach. The benefits of the qualitative research methodology include the support to the researcher to clearly understand the nature and the complications of the event considered, authorise the relation in connection with new research ideas, support the investigation of the event in its environment, as well as analysis of the event. This approach challenges the researcher to explain the data received and draws up conclusions and recommendations (Basias & Pollalis, 2017:94). In the qualitative research methodology, the focus is on interpretation and attention on subjectivity rather than objectivity. The pliability is there in the process of conducting the research study. There might be an orientation to the process, preferably in the outcome and an explicit recognition knock of the research process and on the research circumstances (Munzhelele, 2019:64).

A mixed-method approach is known as the research methodology that integrates qualitative and quantitative research methods. This started in the 1980s when sociologists were trying to solve the differences between qualitative and quantitative models by combining both (Hypotheses, 2019).

The mixed method is recognised as a useful tool to describe and explain complex issues in research. It allows for a more comprehensive and increased underrating of the research questions or objectives. The advantage of using the mixed method is it explores the same study topic.

The mixed method has the following benefits in research:

- Clear understanding of the problem statement.
- Understanding quantitative methods
- It gives more information than using one research method (Hypotheses, 2019).

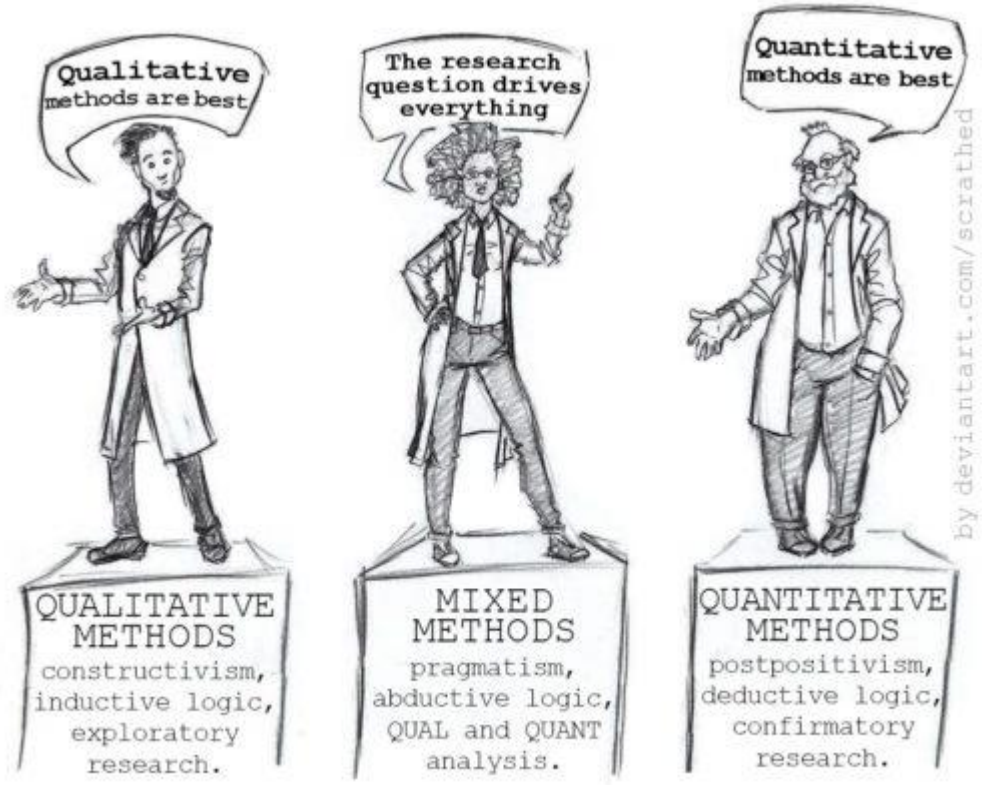


Figure 20: Juxtaposition of three paradigms (Hypotheses, 2019)

3.3 POPULATION

This study is conducted at a mining business in Wadeville, east of Johannesburg, South Africa. The population in this study is individuals who are in operations, sales, and marketing staff, who gave an informed opinion on the research topic. The size of this population is seven people. The operations department consists of engineering and production, while the sales and marketing department includes the logistics department.

From the production department, production reports are used in this study where all production delays are recorded. Maintenance reports/records include costs and downtime of vertical roller mills. Quality control reports, especially on waste caused by

the vertical roller mill, are also included in the technical study. The technical study includes sales and marketing reports on customer complaints.

In terms of the qualitative analysis, purposive sampling is used, where seven individuals within the operations and sales and marketing departments are identified and interviewed. The heads of these departments were approached to identify role players who have sufficient knowledge of maintenance strategies, of the costs and benefits associated with different maintenance strategies, and of the downtime involved in maintenance activities of these mills. The people mentioned by the heads of departments were contacted individually and requested to participate in the study.

3.4 RESEARCH INTRUMENTS

3.4.1 Survey

It is another method that is used to collect consistent data. This is a procedure where data is collected, from a different group of people in the form of face-to-face interviews, telephone interviews, and questionnaires. It is also called the descriptive method to collect data (Martinus, 2018:37).

3.4.2 Questionnaire design

Questionnaires are used to collect data that gives the researcher the necessary information to measure the interests of variables. They can be managed personally, mailed, or distributed to participants. Questionnaires have the following purpose:

- Collect appropriate data.
- Make data equivalent and compliant to make it easier to analyse.
- Reduce bias in asking questions.
- Ask mixed questions (Martinus, 2018:37).

Most interviews are conducted in person, telephonically, or using technology systems such as Skype, Zoom or Microsoft Teams. The face-to-face interview has the advantage of seeing face-to-face expressions and the body language of the participant. The notes must be jotted down during the interview, and this will help in analysing the research portion. Sometimes, participants might be shy or uncomfortable or unfamiliar with the use of the technology or in a face-to-face interview. The following steps must be followed when conducting an interview:

- Participants must be identified in time, and interviews must be scheduled on time.
- Decide whether to use face-to-face interviews or technology such as Skype, Zoom or Microsoft Teams.
- Participants must be notified in time about the facility where the interview will take place.
- Research tools must be tested and in time to avoid disappointments.
- A signed consent form must be obtained.
- A protocol such as ethics approval must be done before conducting interviews (Adhabi & Anozie, 2017: 7).

3.4.3 Planning of research tool

It is very crucial to plan and relate research questions and objectives. It is advisable to involve experts in that field of study to ensure validity of the coverage of questions and objectives as a part of the tool. A literature study must be conducted to identify existing tested questionnaires (Kelley *et al*., 2003:263).

Both quantitative and qualitative research methods make use of collecting data from diverse fields for analysis. The quantitative research method involves survey and experimental designs. For the survey design, the research must determine whether the survey will be cross-sectional by collecting from one point or whether it is longitudinal by collecting data over time. Moreover, the researcher must specify the form of data collection. The self-administrated questionnaires and interviews (recordings, if the participants agree) can be used by the researcher to collect data (Shahi, 2014:93).

The Vb7 condition monitoring tool will be used to find the root cause of vertical roller mill failure/s. Costs before and after this study will be compared. MTBF of the vertical roller mill will be before and after the study. Availability and waste generated by the vertical roller mill will also be compared. Various reports such as production reports, quality control reports, maintenance costs of vertical roller mills, and questionnaires will be used to answer research questions.

Qualitative interviews will be conducted and analysed. The analyses will be conducted by the reviewer. The questionnaire sample (Appendix 1) will be distributed to participants.

3.5 CONCLUSION

In this chapter, the research method was discussed together with the sample population, research instrument and research tool of the study. Ethics were also considered in this chapter. The population of the study was selected from G&W Mineral Resources.

CHAPTER 4: RESULTS AND FINDINGS

4.1 INTRODUCTION

This chapter presents data collected from two vertical roller mills in questionnaires and data gathered from the field.

4.2.1 INTERVIEW RESPONSES FROM PARTICIPANTS

Data collection instrument: Sales and marketing manager

First read through the informed consent form, ask the person whether it is okay to continue with the interview and whether the interview may be recorded for accurate transcription.

1. In which department do you work?
   Sales and marketing.
2. Tell me about your experience and knowledge of the effects of maintenance on vertical roller mills. Please expand.
   We must have continuous maintenance to avoid unnecessary stoppages. Preventive maintenance is crucial to avoid losing customers and reputation.
3. What can you tell me about the vertical roller mills we use? (Prod participant about issues such as operations, cost, efficiency, downtime, etc., whichever falls in his/her area of expertise.)
   These mills allow us to produce a consistent high-quality product, and this is our competitive advantage. Downtime cost us a lot of money, where sometimes we are unable to supply our customers
4. Tell me about the maintenance strategy that is performed on vertical roller mills. (Prod with terms like how often, preventive, corrective… Also, ask whether he/she thinks this is optimal).
   No idea, all I know is that we have issues with our gearboxes.
5. What do you know about the computer maintenance management system on vertical roller mills?
   We use maintenance connection, and schedule maintenance per equipment.
6. Tell me about the suppliers of mills and of spares for vertical roller mills.
   We have suppliers overseas and locally, and they are not always reliable.
7. What is your experience of fault-tracking (root cause analysis) on vertical roller mill failures?

Good fault finding can easily help us to stop for a short period and allow us to sell more product.

8. To what extent are you informed of issues such as production loss, customer complaints and quality issues caused by vertical roller mills? Comment on our communication during/after maintenance in general.
   All customer complains goes to our Customer Service Manager, who will share this with all parties in the operations meeting
9. Tell me what you think about the production and financial effects of vertical roller mill failure and maintenance.
   Financial implication is huge. The impact to our customers if we cannot supply on time have a huge in their businesses.
10. Are there any other issues that we overlook that we should rather consider than looking at the effects of maintenance on vertical roller mills?
    Communication is very important.
11. If you could change anything to make the mills (and the maintenance of these mills) more efficient, what would that be? Please expand.
    Proper maintenance strategy must be implemented quickly so that we can satisfy our customers
12. Is there anything else you would like to mention or discuss?

Vertical roller mill technology is better as compared to ball mills due to consistency of product quality.

Thank you for your valuable inputs. I truly appreciate your time.

4.2.2 INTERVIEW RESPONSES FROM PARTICIPANTS

Data collection instrument: Production manager

First read through the informed consent form, ask the person whether it is okay to continue with the interview and whether the interview may be recorded for accurate transcription.

1. In which department do you work?
   Production
2. Tell me about your experience and knowledge of the effects of maintenance on vertical roller mills. Please expand.

Our mills need attention. Sometimes we produce due to malfunctioning and that manner we can't reach our target and we lose customers

3. What can you tell me about the vertical roller mills we use? (Prod participant about issues such as operations, cost, efficiency, downtime, etc., whichever falls in his/her area of expertise.)

   Maintenance cost is high, and production suffers due to breakdowns. Downtime is costing us fortune. Maintenance team needs to work closely with control room operators should be any changes in operating parameters

4. Tell me about the maintenance strategy that is performed on vertical roller mills. (Prod with terms like how often, preventive, corrective… Also, ask whether he/she thinks this is optimal).

   I am not aware of any maintenance strategy they use, I guess is preventive maintenance, to me this is not enough because we are experiencing downtime on these mills.

5. What do you know about the computer maintenance management system on vertical roller mills?

   It schedules maintenance to be performed in our plant.

6. Tell me about the suppliers of mills and of spares for vertical roller mills.

   I don't have trust on our suppliers, they are not reliable.

7. What is your experience of fault-tracking (root cause analysis) on vertical roller mill failures?

   I don't have experience in fault finding, I am only aware of 5 why method. I don't get involved in any fault of our machines, it is engineering responsibility.

8. To what extent are you informed of issues such as production loss, customer complaints and quality issues caused by vertical roller mills? Comment on our communication during/after maintenance in general.

   We don't get any feedback after maintenance and all customers complains are discussed in our daily operations meeting.

9. Tell me what you think about the production and financial effects of vertical roller mill failure and maintenance.

   Maintenance is poor and it affects our production. Maintenance cost always high, and this affect our profits.

10. Are there any other issues that we overlook that we should rather consider than looking at the effects of maintenance on vertical roller mills?

Communication must be improved between engineering and production, we must together as a team.

11. If you could change anything to make the mills (and the maintenance of these mills) more efficient, what would that be? Please expand.
    Training must be provided to both engineering and production personnel. The issues must be addressed immediately.
12. Is there anything else you would like to mention or discuss?

Nothing

Thank you for your valuable inputs. I truly appreciate your time.

4.2.3 INTERVIEW RESPONSES FROM PARTICIPANTS

Data collection instrument: Engineering manager

First read through the informed consent form, ask the person whether it is okay to continue with the interview and whether the interview may be recorded for accurate transcription.

1. In which department do you work?

Engineering

2. Tell me about your experience and knowledge of the effects of maintenance on vertical roller mills. Please expand.

Not much but I do have an extensive experience on verticals. I have started with the organisation recently.

3. What can you tell me about the vertical roller mills we use? (Prod participant about issues such as operations, cost, efficiency, downtime, etc., whichever falls in his/her area of expertise)

Mills are very old but reliable. The gearboxes that we have are costly to repair and some of the spares are not readily available. Once the gearbox fails it takes almost more than two months to repair and it affects production. This puts pressure on the business as we cannot deliver material on time to customers which is a loss to the business, as there will be less money coming into the *business*.

I think there must be a standard working instruction for operating the machine to help operators know how to operate the machine optimally. Hence, we are milling different products and they behave differently.

4.Tell me about the maintenance strategy that is performed on vertical roller mills. (Prod with terms like how often, preventive, corrective… Also, ask whether he/she thinks this is optimal).

We lack maintenance, job orders are filled but artisans are not honest when conducting inspections. Our team also need skills because most people left the company and skills shortage is a problem.

5. What do you know about the computer maintenance management system on vertical roller mills?

It is a software used to store data for the organisation's maintenance and operations.

6. Tell me about the suppliers of mills and of spares for vertical roller mills.

Some of our suppliers are lacking sense urgency when needed to supply spares during breakdown.

Other suppliers are not reliable and cannot deliver spares on time.

They take a bit longer to supply spares due to where they are situated or located.

7. What is your experience of fault-tracking (root cause analysis) on vertical roller mill failures?

I have a vast experience on doing a root cause analysis. I am the leader of root cause analysis.

8. To what extent are you informed of issues such as production loss, customer complaints and quality issues caused by vertical roller mills? Comment on our communication during/after maintenance in general.

We are informed of any customer complains in our daily operations meeting.

Laboratory personnel take product samples randomly to check the quality of the material if material fail it requires engineering person to adjust settings a call is made to inform him with about the fault and need to rectify it.

9. Tell me what you think about the production and financial effects of vertical roller mill failure and maintenance.

They are expensive to repair on equipment such as gearboxes.

If one mill fail makes it difficult to for the business to reach monthly profits.

10. Are there any other issues that we overlook that we should rather consider than looking at the effects of maintenance on vertical roller mills?

We can look at monitoring our response time to breakdowns.

We can also look into the closing of job cards once the artisans are finished with the job and this will help with capturing machine history

To ensure that contractors fill in our work order then capture it for history and it will assist us during audits that we just retrieve information from the system.

To have checklists for control operators to inspect machines before the start of shift to ensure the machine is in good condition before operating it which will reduce some the delays.

11. If you could change anything to make the mills (and the maintenance of these mills) more efficient, what would that be? Please expand.

Production Foreman to sign off a breakdown work order immediately once an artisan is done with the task.

12. Is there anything else you would like to mention or discuss?

Production should be involved in root cause analysis so that they become aware of the improvements that are being done in the plant and to have their input as well.

Engineering can improve on their job planning when doing assemblies in the machine.

To improve on communication.

Artisan must close all issued work orders immediately when they are done with a breakdown using our maintenance connection software and give a detailed report on what was done.

Production foreman must be called to inspect whether a task performed by an artisan has been carried out as per his/her expectation and test the equipment together. This is to eliminate re-work.

Thank you for your valuable inputs. I truly appreciate your time.

4.2.4 INTERVIEW RESPONSES FROM PARTICIPANTS

Data collection instrument: Fitter 1

First read through the informed consent form, ask the person whether it is okay to continue with the interview and whether the interview may be recorded for accurate transcription.

1. In which department do you work?

   Engineering (Mechanical Workshop).

2. Tell me about your experience and knowledge of the effects of maintenance on vertical roller mills. Please expand.

   Firstly, machines are very old and need attention frequently, if a component is broken instantly. It needs to be attended to immediately as it affects other component to malfunction, and product fail when doing quality check.

3. What can you tell me about the vertical roller mills we use? (Prod participant about issues such as operations, cost, efficiency, downtime, etc., whichever falls in his/her area of expertise)

   Vertical roller mills are heavy machinery in which if one component breaks it can cost a lot of money, a huge production loss and even operations need attention. In my experience in the past, we have lost some customers due to unbale to supply to customers' demand.

4. Tell me about the maintenance strategy that is performed on vertical roller mills. (Prod with terms like often, preventive, corrective… Also, ask whether he/she thinks this is optimal).

   We grease and top up oil on a weekly basis this done on critical components to prevent failures. There is no defined maintenance strategy for our vertical roller mills

5. What do you know about the computer maintenance management system on vertical roller mills?

   Data is stored in the maintenance connection to assist in scheduling maintenance. Work orders can be created for breakdowns. Work orders are prefilled and can be generated when are due for issuing

6. Tell me about the suppliers of mills and of spares for vertical roller mills.

We have suppliers that are consistent, and others are not. Other suppliers believe that we are only relying on them. Spares like thrust bearing can only be bought in overseas.

7. What is your experience of fault-tracking (root cause analysis) on vertical roller mill failures?

   PLC has made it easier to diagnose a fault. It has reduced the amount of time trying to figure out a fault. It gives you a direction of where to focus on or pay attention to.

8. To what extent are you informed of issues such as production loss, customer complaints and quality issues caused by vertical roller mills? Comment on our communication during/after maintenance in general.

   We are always informed if we get customer complaints, and it helps to improve on customer satisfaction.

9. Tell me what you think about the production and financial effects of vertical roller mill failure and maintenance.

   I think engineering need to be given time to do maintenance tasks to prevent failures. If the machine breaks, we lose production, and it leads to financial loss

10. Are there any other issues that we overlook that we should rather consider than looking at the effects of maintenance on vertical roller mills?

    Building teamwork culture. Ignoring maintenance due being behind with production.

11. If you could change anything to make the mills (and the maintenance of these mills) more efficient, what would that be? Please expand.

    Fault finding. Ensure that commissioning is done properly by handing over to production

12. Is there anything else you would like to mention or discuss?

    Communication in the team. Each department need to strive to reach their goal. To avoid downtime by assisting each other. Be given a guideline on what to do on breakdowns. Guideline on major assemblies.

Thank you for your valuable inputs. I truly appreciate your time.

4.2.5 INTERVIEW RESPONSES FROM PARTICIPANTS

Data collection instrument: Fitter 2

First read through the informed consent form, ask the person whether it is okay to continue with the interview and whether the interview may be recorded for accurate transcription.

1. In which department do you work?

   Mechanical Workshop.

2. Tell me about your experience and knowledge of the effects of maintenance on vertical roller mills. Please expand.

   The main problem of this roller mills are gearboxes. Other components are easy to maintain. The other critical component is the classifier, if it is not working properly the product specification fails.

3. What can you tell me about the vertical roller mills we use? (Prod participant about issues such as operations, cost, efficiency, downtime, etc., whichever falls in his/her area of expertise)

   When thy are down for maintenance, they cost lot of money. We are unable to supply our customers. The cost of spares is very high as some spears can only be found internationally.

4. Tell me about the maintenance strategy that is performed on vertical roller mills. (Prod with terms like often, preventive, corrective… Also, ask whether he/she thinks this is optimal).

   I cannot clearly define maintenance strategy we have, I can call it run to failure maintenance strategy because sometimes we don't do proper maintenance unless it is a serious breakdown.

5. What do you know about the computer maintenance management system on vertical roller mills?

   We use maintenance connection to schedule our maintenance.

6. Tell me about the suppliers of mills and of spares for vertical roller mills.

   Our suppliers are not reliable; spares took long to fabricate. It can easily take months for us to get spares

7. What is your experience of fault-tracking (root cause analysis) on vertical roller mill failures?

We mostly use PLC, and sometimes PLC does not give clear indication of the fault. On mechanical faults sometimes it is difficult to find a fault.

8. To what extent are you informed of issues such as production loss, customer complaints and quality issues caused by vertical roller mills? Comment on our communication during/after maintenance in general.

   Depending on how big the problem is, we get information from our manager or control room operators on quality issues, and job cards is given to us to attend the problem

9. Tell me what you think about the production and financial effects of vertical roller mill failure and maintenance.

   The company is losing money when this vertical roller mills are on breakdown. We were informed that we have lost customers due to unavailability of product to our customers.

10. Are there any other issues that we overlook that we should rather consider than looking at the effects of maintenance on vertical roller mills?

    Communication among us needs to improve. Feedback must be given to us at least once a week on the performance of the plant.

11. If you could change anything to make the mills (and the maintenance of these mills) more efficient, what would that be? Please expand.

    We need to find proper maintenance, especially on our gearboxes.

12. Is there anything else you would like to mention or discuss?

No

Thank you for your valuable inputs. I truly appreciate your time.

4.2.6 INTERVIEW RESPONSES FROM PARTICIPANTS

Data collection instrument: Electrician 1

First read through the informed consent form, ask the person whether it is okay to continue with the interview and whether the interview may be recorded for accurate transcription.

1. In which department do you work?

Engineering (Electrical Workshop)

2. Tell me about your experience and knowledge of the effects of maintenance on vertical roller mills. Please expand.

   Reduction in downtime, reduce equipment repair, better production and prolongs life span of machines.

3. What can you tell me about the vertical roller mills we use? (Prod participant about issues such as operations, cost, efficiency, downtime, etc., whichever falls in his/her area of expertise)

   Very reliable but requires maintenance. They can produce more than they are producing currently. They are a high cost but can give high production output. It takes longer to restore as it requires highly intensive labour.

4. Tell me about the maintenance strategy that is performed on vertical roller mills. (Prod with terms like how often, preventive, corrective… Also, ask whether he/she thinks this is optimal).

   It is structured by maintenance connection. It prioritizes as per task urgency. Priorities are mixed up.

5. What do you know about the computer maintenance management system on vertical roller mills?

   A tool to print out work orders.

6. Tell me about the suppliers of mills and of spares for vertical roller mills.

   Machines are imported but spares are available locally and internationally. It is a battle to get spares in time from all suppliers.

7. What is your experience of fault-tracking (root cause analysis) on vertical roller mill failures?

   Familiar with Root Cause Analysis on the vertical roller mill. I have an extensive knowledge on the vertical roller mill. I hardly struggle to do a fault finding on the machines on electrical faults only.

8. To what extent are you informed of issues such as production loss, customer complaints and quality issues caused by vertical roller mills? Comment on our communication during/after maintenance in general.

   We are only told when the situation is worse. There is no benchmark.

9. Tell me what you think about the production and financial effects of vertical roller mill failure and maintenance.

Spares takes long to arrive on site. If there is a major breakdown on the machine, it takes approximately 3 months or more to restore the plant which equates to 3-months production loss.

10. Are there any other issues that we overlook that we should rather consider than looking at the effects of maintenance on vertical roller mills?
    Standardize how the control operators are operating the machines. Introduce an efficient method of reporting breakdowns.

11. If you could change anything to make the mills (and the maintenance of these mills) more efficient, what would that be? Please expand.
    Install automation system that will improve our alarm or fault response time as it takes a bit longer for the SCADA to report a fault on the screen. Live monitoring dashboard outside the control room. It will assist with monitoring the plant performance on an hourly basis. It will enable us to see how the equipment is operated. Optimize the running of the plant.

12. Is there anything else you would like to mention or discuss?
    Correct maintenance must be done to avoid downtime. Availability of vertical roller mills must improve.

Thank you for your valuable inputs. I truly appreciate your time.

4.2.7 INTERVIEW RESPONSES FROM PARTICIPANTS

Data collection instrument: Electrician 2

First read through the informed consent form, ask the person whether it is okay to continue with the interview and whether the interview may be recorded for accurate transcription.

1. In which department do you work?

Engineering (Electrical Workshop)

2. Tell me about your experience and knowledge of the effects of maintenance on *vertical roller mills. Please expand.*

Is to keep it running with minimal downtime. In this, will be able to control on when and how long will or must a mill stop for maintenance.

3. What can you tell me about the vertical roller mills we use? (Prod participant about issues such as operations, cost, efficiency, downtime, etc., whichever falls in his/her area of expertise)

   They are more reliable in terms of production. It has the advantage of high grinding efficiency, low noise, and little dust pollution if maintenance is done correctly. Our main issue is gearbox failures.

4. Tell me about the maintenance strategy that is performed on vertical roller mills. (Prod with terms like how often, preventive, corrective… Also, ask whether he/she thinks this is optimal).

   There is a weekly planned maintenance which is preventive that is of course optimal.

5. What do you know about the computer maintenance management system on vertical roller mills?

   Maintenance connection plan and print out job cards.

6. Tell me about the suppliers of mills and of spares for vertical roller mills.

   Suppliers are not reliable; they took tome to manufacture or supply critical spares.

7. What is your experience of fault-tracking (root cause analysis) on vertical roller mill failures?

   I can only fault find when a soft starter fails and trips which mostly, we work with the fitter to trace the fault, I'm clueless in gearboxes where most failures occur.

8. To what extent are you informed of issues such as production loss, customer complaints and quality issues caused by vertical roller mills? Comment on our communication during/after maintenance in general.

   It is mostly production loss caused by downtime and quality issues from the lab when the mill is in operation. We are only informed if there is quality issues or customer complains.

9. Tell me what you think about the production and financial effects of vertical roller mill failure and maintenance.

   The effects are negative production which affect the financial aspects of the company.

10. Are there any other issues that we overlook that we should rather consider than looking at the effects of maintenance on vertical roller mills?

By taking care of people who service the mills. A happy employee is productive employee.

11. If you could change anything to make the mills (and the maintenance of these mills) more efficient, what would that be? Please expand.
    A planned maintenance measures. At a particular day or time. A mill will stop and for that time, an electrician, fitter, and boilermaker must attend to the mill for that planned time.

12. Is there anything else you would like to mention or discuss?
    No

Thank you for your valuable inputs. I truly appreciate your time.

4.2.8 SUMMARY OF FINDINGS FROM PARTICIPANTS

The two vertical roller mills are too old, and the organisation experienced a great deal of downtime on vertical roller mills, and which resulted in not achieving set targets for the month and losing customers. Most failures of these vertical roller mills are gearboxes. Poor maintenance has a negative impact in production, and therefore a proper maintenance strategy must be implemented to avoid downtime, including checklists for operators. If the classifier does not work properly, the product does not meet the required specifications. The mills must be maintained to avoid stoppages, also to achieve customer satisfaction and on-time delivery. The spares are very expensive, and they are not available on the shelf, they need to be machined first. For some spares, such as a thrust bearing, lead time is long. Suppliers of spares are locally and internationally. Some participants do not have trust in these suppliers, because they are not reliable, and they lack urgency. Some artisans are not honest when they do inspections, and a lack of skills has also been identified as a barrier. Some artisans cannot define maintenance strategy; they think greasing is a maintenance strategy, while some participants responded by saying a maintenance strategy is preventive maintenance. Most participants are aware that the organisation is using maintenance connections to schedule maintenance. The engineering manager is the leader of root cause analysis; he is familiar with 5 WHY. Root cause analysis is not often carried out. Electricians rely on PLC to do fault finding, and they are not familiar with fault finding on the gearboxes. All customer complaints are discussed in the operations meeting if there are any. Engineering does not properly communicate this with customer; they

only know if the situation gets worse. Communication between production and engineering must be improved

4.3 BREAKDOWN OF VERTICAL ROLLER MILLS FAILURES

The data below was collected from 2018 until 2020. The failures of vertical mills are also categorised.

Table 2: Vertical roller mill failures

Mill	**Location**	**2018**	**2019**	**2020**
Mill 1	White section	2	4	5
Mill 6	White section	1	3	4
Total		**3**	**7**	**9**

4.3.1 Classification of failures

A: Gearbox failures

B: Electric motors

C: Classifier / separator

Table 3: Vertical roller mill failures per category

Categories	**2018**	**2019**	**2020**
A	2	4	6
B	1	2	2
C	0	1	1
Total	3	7	9

4.3.2 Total maintenance costs and downtime

When the equipment is on downtime, it causes operations crews to become idle. Downtime causes disruption of activities and loss of productivity. The equipment

downtime consists of administrative and maintenance times, including delays to supply product to the customers. The administrative time includes hours taken to report the equipment breakdown and direction of what needs to be done. The maintenance hours include hours taken to restore the equipment to its operating conditions. The supply delays are due to a lack of spare part availability to perform maintenance.

The breakdown costs are divided into two categories, namely:

- Tangible costs, which are labour costs, materials and other resources required to perform maintenance activities.
- Intangible costs, which are costs from idling of other equipment, operations crew idling and factors that impact organisation such as loss of profitability and unhealthy customer relationships (Kumar & Mouli, 2019: 227).

Table 4: Vertical roller mill downtime costs and hours

	Downtime costs in rands			Downtime in hours		
Failure classification	**2018**	**2019**	**2020**	**2018**	**2019**	**2020**
A	R0,726m	R1.874m	R2.73m	1794	1975	4384
B	R0,034m	R0,070m	R0,035m	6	17	20
C	R0m	R0.036m	R0,036m	0	16	12
Total	**R0.7603m**	**R1.98m**	**R2.81m**	**1800**	**2008**	**4416**

The information above was extracted from Syspro and daily production reports. The daily production report is accessible from our share drive, while maintenance costs are available from the finance department on request. The monthly maintenance cost/report is sent to the engineering manager monthly.

In the mining industry, maintenance costs can account for almost 40% of the operational budget. It is very crucial to improve maintenance costs for financial savings. In today's market, industries must be capable of satisfying customers to be competitive. To achieve all this, industries are forced to increase equipment availability and reliability. The role of any organisation is to increase profitability year on year for the shareholders. Therefore, maintenance and assets management can increase profitability by minimising operating costs of the organisation and maximising capability. The total cost of any organisation depends on the quality of the equipment and the way it is being utilised, maintenance policy and maintenance.

To develop a maintenance strategy and make it valuable to the organisation the following is needed:

- A detailed plan on what must be done on each component of the machinery.
- Getting the right people with the right skills to operate and maintain the machinery.
- Implementation and monitoring of the chosen maintenance strategy (Eti *et al*., 2006:1236)

4.4 TRIBOLOGY

Lubrication is the lifeblood of any gearbox. It is very important to carry out certain tasks to keep the gearbox in good working condition. Tribology is one of the common tools used by many industries to maintain the life of the equipment.

The role of lubrication is to lubricate moving parts of the gearbox. Lubrication reduces friction and wears, as this is the amount of energy needed to perform the work. When the correct lubrication is used, the correct load is applied, and this simply means that wear will not occur. Inadequate lubrication is not good for the gearbox or when the load increases. When the load increases, lubrication degrades. This leads to oil film thickness not being capable of separating friction surfaces.

Selecting the correct lubrication, along with careful maintenance of the lubricant. It is very important to ensure proper adequate protection to a piece of equipment. Oil analysis is the most constructive way to extend the useful life of lubricants while maintaining extra protection for a piece of equipment (Sankar *et al*., 2012:304).

Oil analysis tests provide information that can be broken down into the following categories:

- Lubrication condition: An examination of lubrication condition that tells whether the system oil is healthy and fit for further service or change.
- Contamination: This is mostly caused by the surrounding environment in a dirt form or water, including contamination from the process that led to premature machine failure. Contamination gives the user an alert or action to avoid unnecessary equipment failures.
- Machine wear: If the machine is not in a good condition, it generates wear particles at an exponential form. This can be avoided by constantly taking oil samples and analysing them (Michaelis *et al*., 2011:48).

The value of tribology can only be seen if the sample is collected and analysed continuously. The oil analysis gives crucial information about the condition of the gearbox, including contamination. For the mine to reduce its operating costs, the focus must be on increasing reliability and availability of the machinery and maintenance costs (PS, 2014).

The results of oil analysis below were taken before and after mill 1 and 6 repairs.

Sample Information.					OIL ANALYSIS						
Sample Number	Bottle Number	Register Date	Sample Date	SMR	Oil Read	Filter Read	Oil Chng	Filter Chng	Oil Topup	Oil Supplier	Oil Grade
688193	675435	2021-05-28	2021-05-21				N	N	N	SHELL	320
681160	675421	2021-04-14	2021-04-09				N	N	N	SHELL	320

Comments. Recommended Action. Feedback.

- Sample No.688193 - Status 1

COMMENTS: High silicon readings alone does not indicate dust ingress. Possibly traces of a silicon gasket material. Wear rates are normal.

ACTION: Defer action on next sample submitted.Resample at regular intervals to monitor the oil condition and wear trend.

TAKEN BY: LINDELO

- Sample No.681160 - Status 4

COMMENTS: A large increase in wear levels noted - possible failure in progress. Excessive dust (Si, Al) and water contamination are evident. Visible magnetic wear sediment noted in the sample.

ACTION: Drain and FLUSH. Check gearbox components for excessive wear. Check breather and seals for dust and water entry. Action as required.Resample at regular intervals to monitor the oil condition and wear trend.

TAKEN BY: LAWRENCE

Figure 21: Mill 1 oil analysis and results

Sample Information.					OIL ANALYSIS						
Sample Number	Bottle Number	Register Date	Sample Date	SMR	Oil Read	Filter Read	Oil Chng	Filter Chng	Oil Topup	Oil Supplier	Oil Grade
688195	675439	2021-05-28	2021-05-21				N	N	N	SHELL	320
681161	675412	2021-04-14	2021-04-09				N	N	N	SHELL	320

Comments. Recommended Action. Feedback.

- Sample No.688195 - Status 1

COMMENTS: High silicon readings alone does not indicate dust ingress. Possibly traces of a silicon gasket material. Wear rates are normal.

ACTION: Defer action on next sample submitted.Resample at regular intervals to monitor the oil condition and wear trend.

TAKEN BY: LINDELO

- Sample No.681161 - Status 4

COMMENTS: A large increase in wear levels noted - possible failure in progress. Excessive dust (Si, Al) and water contamination are evident. Visible magnetic wear sediment noted in the sample.

ACTION: Drain and FLUSH. Check gearbox components for excessive wear. Check breather and seals for dust and water entry. Action as requiredResample at regular intervals to monitor the oil condition and wear trend.

TAKEN BY: LAWRENCE

Figure 22: Mill 6 oil analysis and results

4.4.1 Oil contamination

Oil contamination analysis can easily disclose worsening or failure of the oil, contamination of the gearbox with water or particulate debris, and wear of the lubricated gearbox. These impurities can be easily seen by doing a visual inspection of samples. The water can be seen in an oil sample as a distinct water layer. The cleanliness of the oil can be established by a visual test of the sample. After filtration of the oil, debris must be visually discovered before the microscopic test. The presence of water from an oil sample can also be detected using filter paper used in oil analysis.

The water can easily affect the viscosity of oil by reducing the effect of oil, and this can result in increasing the wear rate of the gearbox. The most common minerals that contaminate gearbox units are coal, silica, and shale. This mineral produces fine abrasives wear particles that can only be discovered using a microscope. The mineral particles in suspension normally act as a grinding medium, which creates bearing wear that can easily affect the shaft if it is not picked up at an early stage (PS, 2014).

The picture below was taken from mill 6 after hydraulic pump failure due to contamination.

Figure 23: Mill 6 gearbox contamination

4.5 ROOT CAUSE FAILURE ANALYSIS

Unplanned stoppages have a huge effect on the business profitability, production loss, opportunities to get new business and increased maintenance costs. To maximise plant availability, most industries implement various reliability improvement actions such as root cause failure analysis (RCFA). The objective of RCFA is to identify the root cause and prevent reoccurrence. To carry out RCFA, individuals must have proper understanding of identifying all possible failures, and analysing these to come up with a proper solution to the problem (Hussin *et al*., 2016:13372)

During the RCFA, it was discovered that there was a great deal of material that was spilling from the table due to the segments that were worn out. The RCFA actions will be discussed in the next chapter.

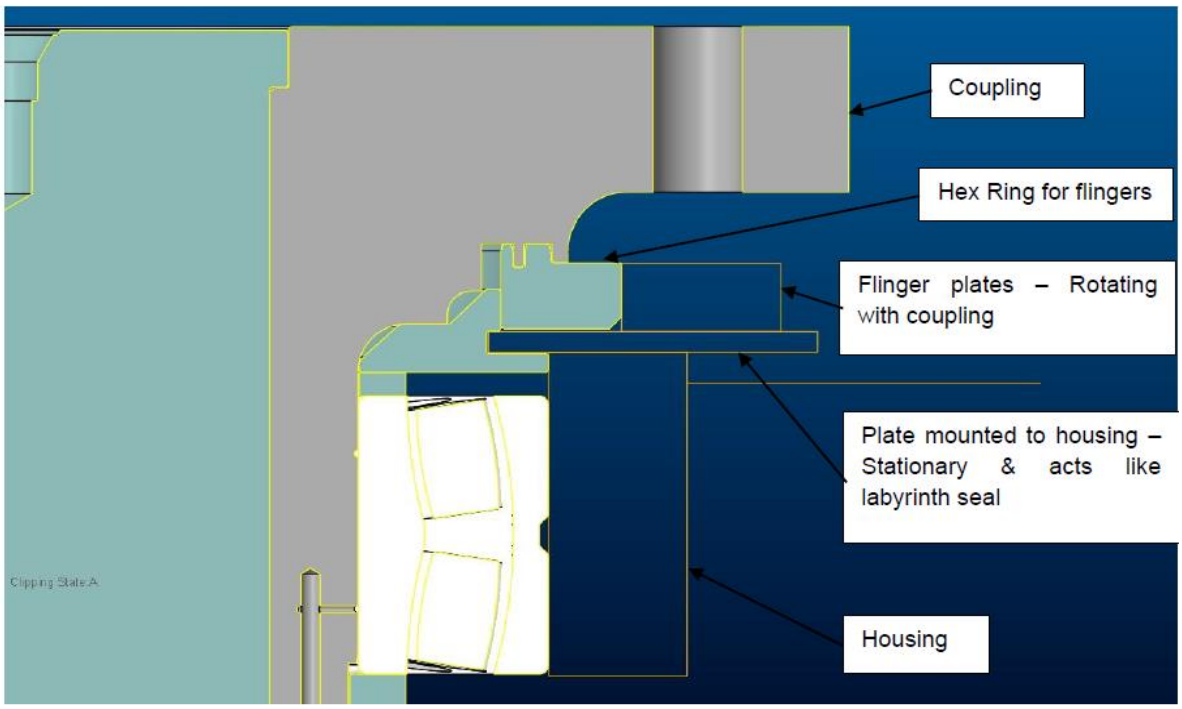


Figure 24: Current sealing arrangement

The adjustment was made to the segment to achieve a 3 mm gap between the segment and rotating table. The output seal was also modified to prevent the product going inside the gearbox. The picture below shows the new seal arrangement to prevent dust from going inside the gearbox.

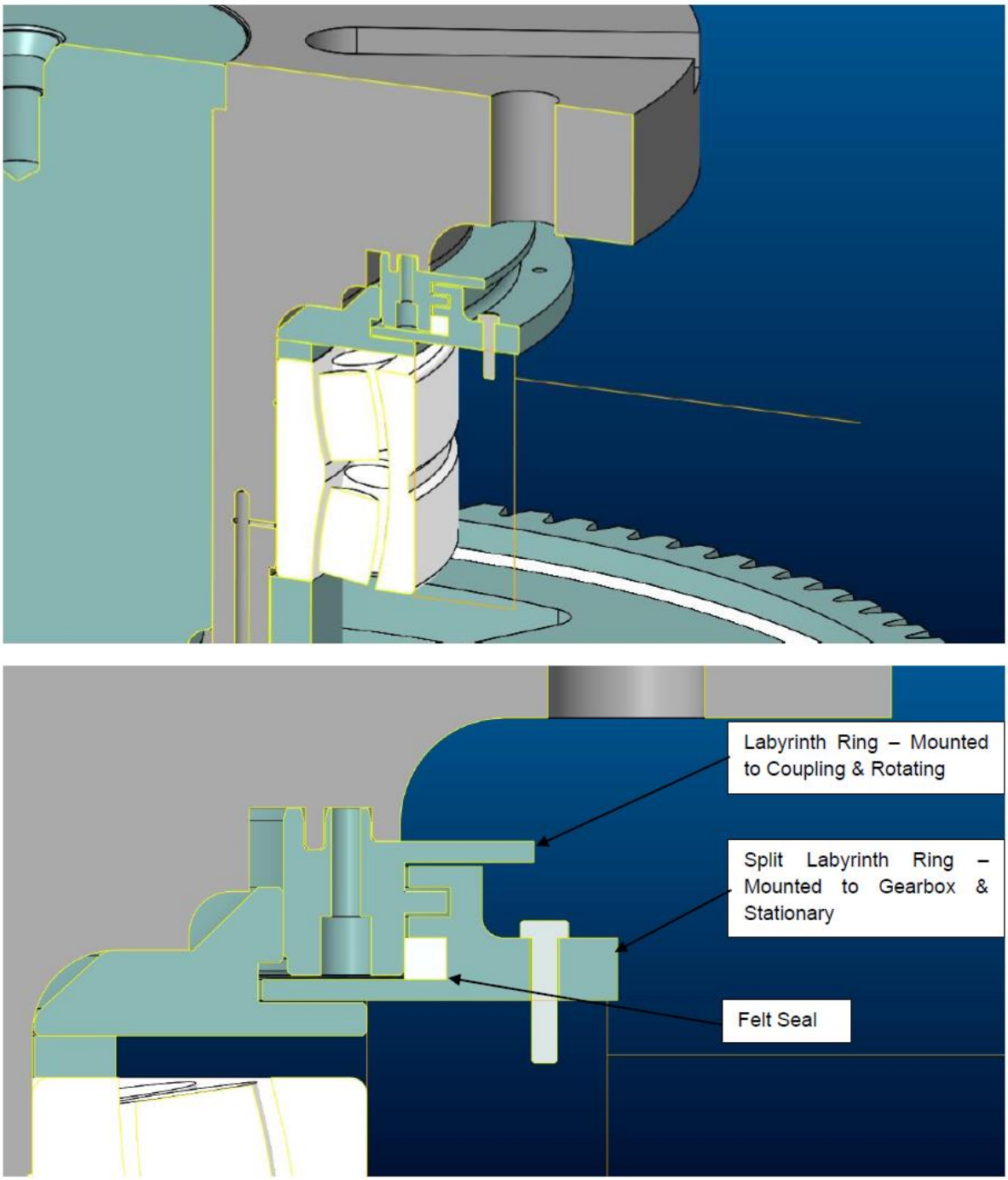


Figure 25: New sealing arrangement

After modifying out sealing, a huge improvement was recognised through oil analysis results that came back clean. Adjustment of the segment also made a huge improvement, i.e., no spillages from the gearbox.

4.6 VIBRATION ANALYSIS

Vibration analysis was developed over a period of approximately 50 years. The condition monitoring of the gearbox is a very important task due to its power transmission in industries. Numerous techniques have been developed, such as wear and debris analysis and acoustics. Vibration analysis is regarded as one of the most crucial condition monitoring techniques applied in real life. The defects experienced in rotating machineries give off vibration patterns, and that is where faults are identified using vibration signature analysis. This technique is capable of recording and identifying vibration signatures for monitoring gearboxes. Vibration analysis is conducted by using transducers to compute acceleration, velocity, or displacement (Diwakar *et al*., 2012:123).

The technique to diagnosis a gear is based on the vibration signed from the gearbox casing. The objective is to detect faults on the gearbox at an early stage of development so that the life of the equipment can be estimated. The crucial parts in gear vibration spectra are gear meshing frequency and harmonics. The increase in number, including amplitude, such as sidebands, can indicate a fault. Generally, in gearboxes, impact and friction occur, where a single crack can easily change the speed once the teeth are in the load zone. The result of this is impact, and if the lubrication on the teeth is not enough, friction will occur. Vibration monitoring can detect impact and friction in predictive maintenance (Dynapar, 2017).

Figure 26 Damaged mill 1 input cartridge gear

The figure above was taken from mill 1, after the gearbox failed to drive the grinding table.

4.6.1 Results of condition monitoring

The condition monitoring results below show that both mills are running at acceptable levels. Condition monitoring is part of predictive maintenance. The results show that there is no gear or bearing damage. For the results showed below, the motor was taken as a reference, which simply means that if there is damage, it will show in the results taken from electric motor.

Laser engineering

Condition Monitoring Report

Condition Monitoring conducted for:

Company	: GW MINERALS
Site	: WADEVILLE
Date	: 09/07/2021
Analysts	: Pieter Erasmus
Cell Number	: 074 466 7143
Tel Number	: 016 428 3822
Fax Number	: 086 544 9537
E-mail	: Pieter@laseralignment.co.za
Report Number	: Laser Eng. 09-07-21

Company Registration No: CK/87/28229/23 VAT Registration No: 4500127727
14 Mint Street Arcon Park 1949, P O Box 3099, Vereeniging, 1930
Tel: +27 16 428 3822 Emergency: +2782 653 1854 (24 Hrs.) Fax: 086 544 9537 Int. Fax: +27 16 427 1002
Accounts: Kina Van Niekerk Cell No: +27 (0) 82 603 7143 Email: info@laseralignment.co.za

Aligned to your needs

PRIORITY COUNT

GREEN : NO ACTION
ORANGE : BORDERLINE ACTION
RED : ACTION REQUIRED

Condition Monitoring Summary Report

Site: GW MINERALS MILL 1

MILL 1:			
Machine	**Equipment**	**Priority**	**Page**
MILL 1	Motor	NO ACTION	3-4

Site: **GW MINERALS MILL 1**

Machine: MILL 1 – Motor DE

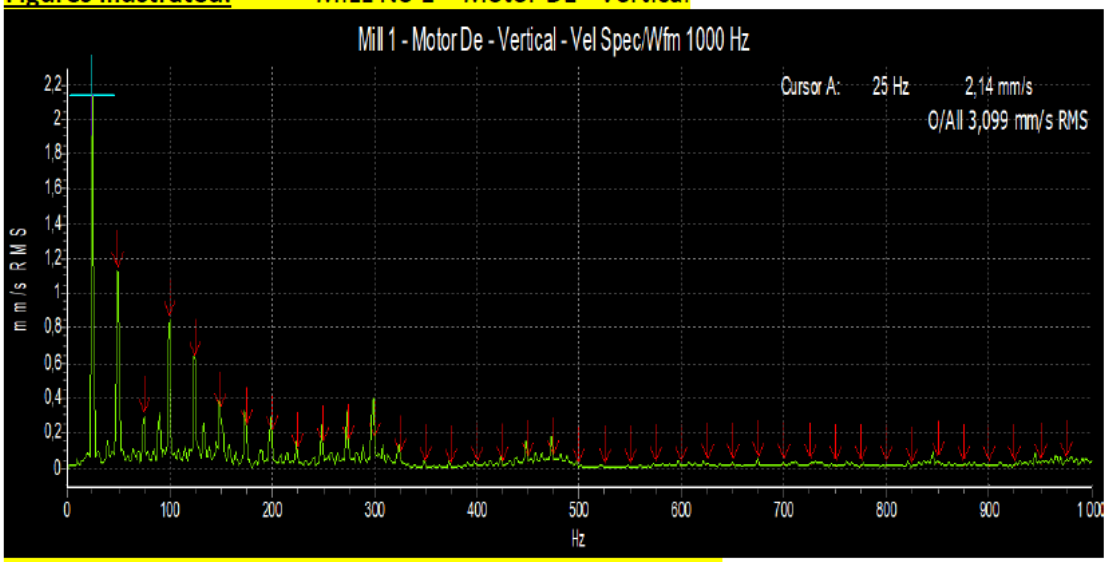
Survey Results: NDE VERTICAL: Overall vibration is running at 2,14 mm/s with a RMS Reading of 3,099 mm/s.

Survey Results: NDE HORIZONTAL: Overall vibration is running at 1,093 mm/s with a RMS Reading of 2,733 mm/s.

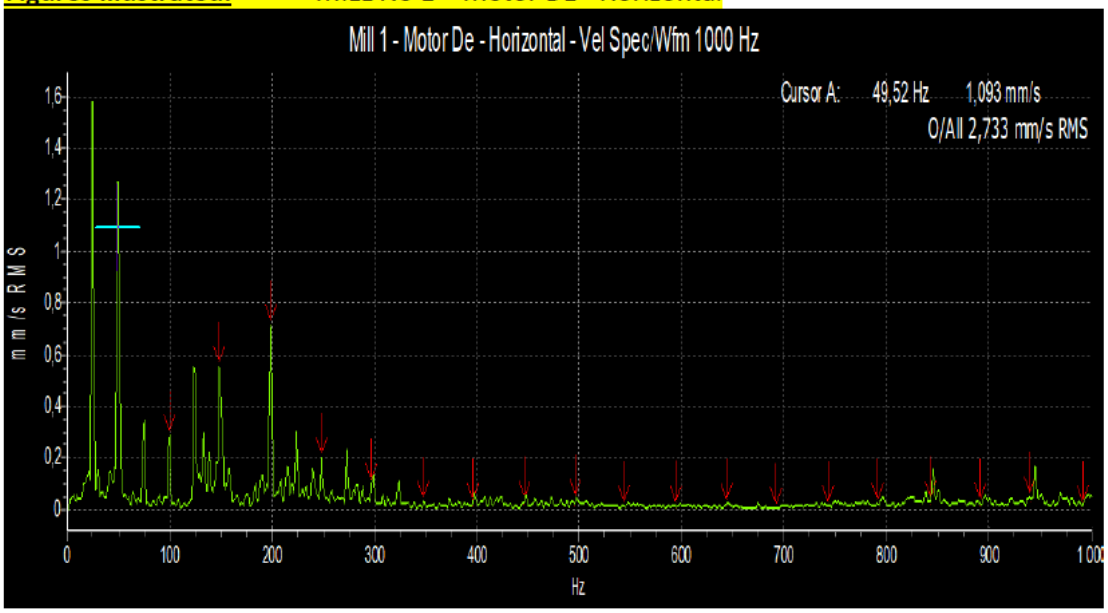
Recommendations:

- No action required.

Figures Illustrated: MILL No 1 – Motor DE - Vertical



Figures Illustrated: MILL No 1 – Motor DE - Horizontal



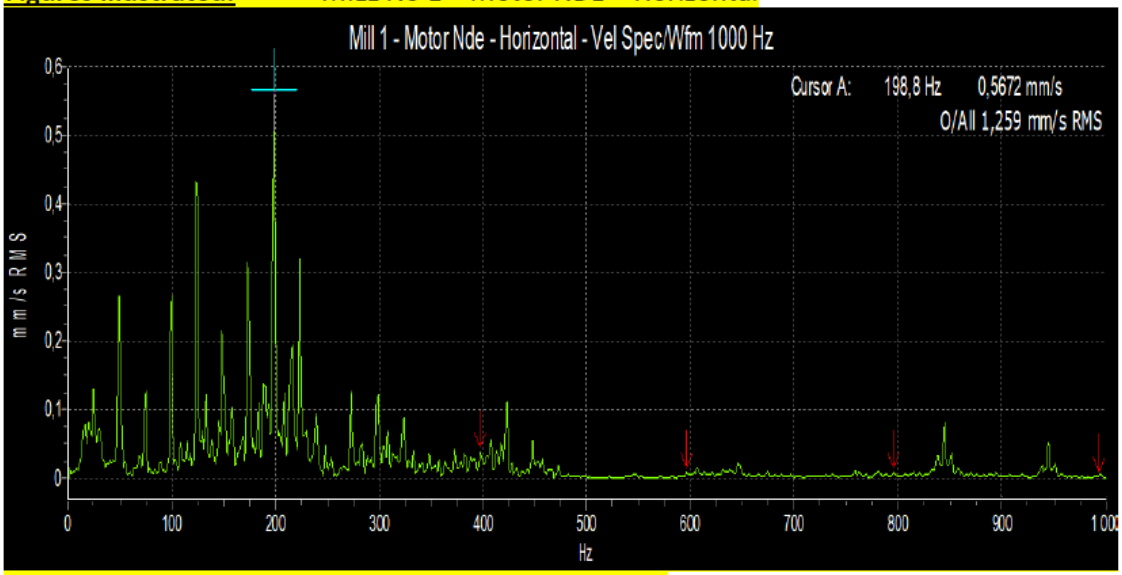
Site: **GW MINERALS MILL 1**
Machine: MILL No 1 – Motor NDE

Survey Results: NDE HORIZONTAL: Overall vibration is running at 0,5672 mm/s with a RMS Reading of 1,259 mm/s.
Survey Results: NDE VERTICAL: Overall vibration is running at 0,9553 mm/s with a RMS Reading of 1,931 mm/s.

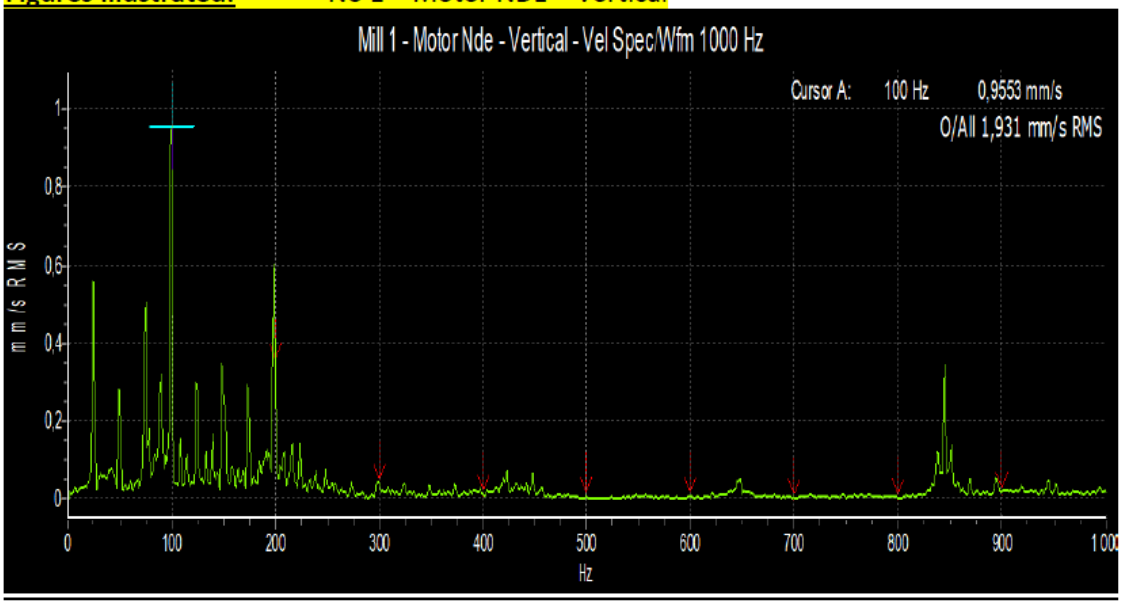
Recommendations:

- No action required.

Figures Illustrated: MILL No 1 – Motor NDE – Horizontal



Figures Illustrated: No 1 – Motor NDE – Vertical



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Accounts: Kina Van Niekerk Cell No: +27 (0) 82 603 7143 Email: info@laseralignment.co.za

Aligned to your needs

PRIORITY COUNT

GREEN : NO ACTION
ORANGE : BORDERLINE ACTION
RED : ACTION REQUIRED

Condition Monitoring Summary Report

Site: GW MINERALS MILL 6

MILL 6:			
Machine	**Equipment**	**Priority**	**Page**
MILL 6	Motor	NO ACTION	3-4

Site: **GW MINERALS MILL 6**

Machine: MILL 6 – Motor DE

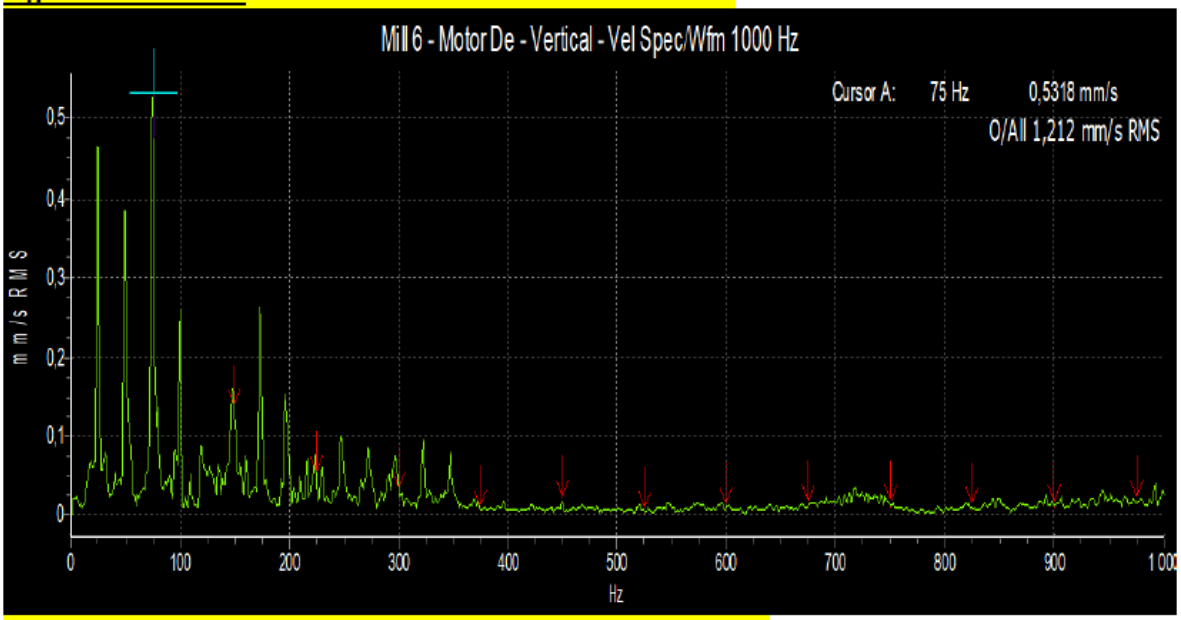
Survey Results: NDE VERTICAL: Overall vibration is running at 0,5318 mm/s with a RMS Reading of 1,212 mm/s.

Survey Results: NDE HORIZONTAL: Overall vibration is running at 1,66 mm/s with a RMS Reading of 2,148 mm/s.

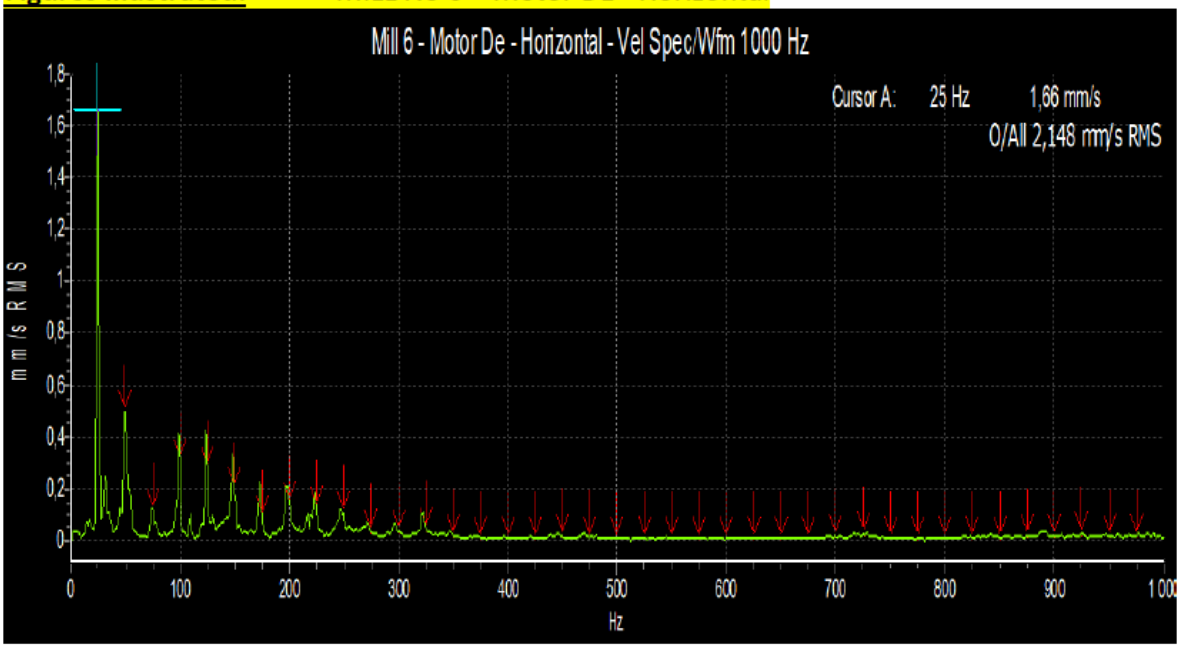
Recommendations:

- No action required. Machine is giving a vibration spike on 75 HZ this is due to crushing in progress.

Figures Illustrated: MILL No 6 – Motor DE - Vertical



Figures Illustrated: MILL No 6 – Motor DE - Horizontal



Site: **GW MINERALS MILL 6**

Machine: MILL No 6 – Motor NDE

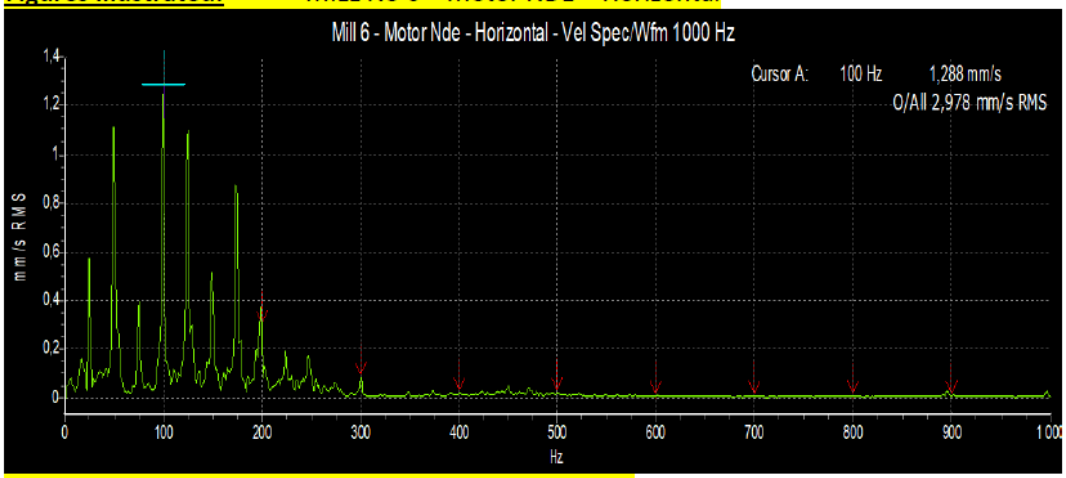
Survey Results: NDE **HORIZONTAL:** Overall vibration is running at 1,288 mm/s with a RMS Reading of 2,978 mm/s.

Survey Results: NDE **VERTICAL:** Overall vibration is running at 1,702 mm/s with a RMS Reading of 2,441 mm/s.

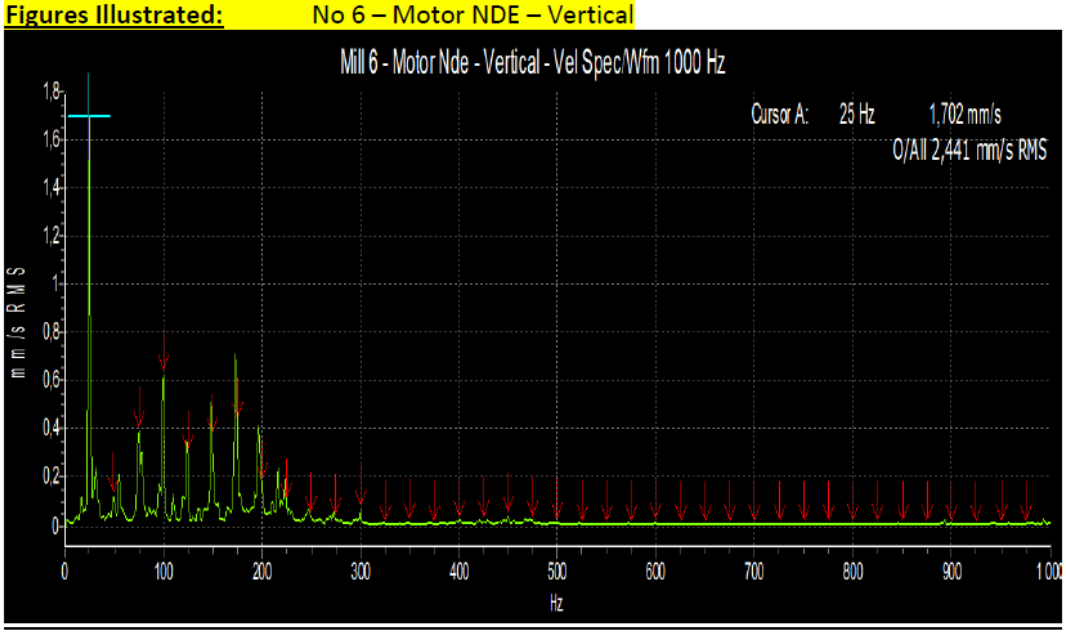
Recommendations:

- No action required. Machine is giving a vibration spike on 100 HZ this is due to crushing in progress.

Figures Illustrated: MILL No 6 – Motor NDE – Horizontal



Figures Illustrated: No 6 – Motor NDE – Vertical



4.7 SUMMARY OF FINDINGS FROM THE FIELD DATA

Vibration monitoring was taken on two occasions, and everything was found to be in order. All vibration readings are within the limits of the gearbox, which means no further action is required. The output finger plate was replaced with a modified split labyrinth ring mounted to the gearbox to prevent product from going inside the gearbox, as shown in Figure 23. Figure 23 shows contamination of oil and product.

4.8 CONCLUSION

The following chapter will answer the research questions and objectives. A suitable maintenance strategy for the organisation will also be discussed based on the literature discussed in Chapter 2.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

Most failures of these vertical roller mills are gearboxes. Poor maintenance has a negative impact in production, and therefore a proper maintenance strategy must be implemented to avoid downtime. The main concern of the organisation is high maintenance on vertical roller mills and product quality issues. Communication is also identified as a gap; quality issues are not shared with employees, especially with maintenance teams. Spare parts also contribute to delays in getting vertical mills repaired in time. MTTR is a concern because suppliers take time to manufacture or deliver spares as some spares can only be obtained from overseas. Suppliers of spares are locally and internationally. Some participants do not trust these suppliers, because they are not reliable, and they lack urgency. Some artisans cannot define maintenance strategy; they think greasing is a maintenance strategy, while some participants responded by saying a maintenance strategy is preventive maintenance. Most participants are aware that the organisation is using maintenance connection to schedule maintenance.

Vibration monitoring was taken on two occasions, and everything was found to be in order. All vibration readings are within the limits of the gearbox, which means no further action is required.

This mineral produces fine abrasive wear particles that can only be discovered using a microscope. The minerals particles in suspension normally act as a grinding medium that creates bearing wear, which can easily affect the shaft if it is not picked up at an early stage. Regular oil sampling helps to detect contamination at an early stage. The output finger plate was replaced with a modified split labyrinth ring mounted to the gearbox to prevent product from going inside the gearbox. The modification of the output had a huge contribution in preventing product from going into the gearbox. The 3mm gap adjustment of the segment prevented spillages from the table when the vertical roller mill is in operation.

The organisation is not in the position to keep high value spares in stock as this will affect their DWC. The shareholders are very strict regarding all operations within the group to achieve their DWC target.

5.2 PRIMARY RESEARCH QUESTION

- To investigate which maintenance strategy should be used to increase the reliability and availability of vertical roller mill technology at the lowest total cost.

Condition monitoring (CM) is the process of obtaining the status of the machinery and predicting the capability of the system at any given stage. Prediction and diagnosis based on CM give a better indication of plant maintenance tasks. Condition-based maintenance using machinery condition assessment has several advantages compared to time-based or reactive maintenance, mainly in terms of minimal downtime and maintenance costs. Vibration analysis is one of the condition monitoring methodologies.

The objective of predictive maintenance is simply to warrant proactive scheduling of remedial work and to prevent unexpected equipment downtime. Accurate equipment performance results can only be obtained while the equipment is running. This can be achieved by connecting sensors to the equipment to record different readings such as temperature and control voltage.

5.2.1 Secondary research questions

- To determine the effect of maintenance on availability through a literature study.

As stated in 2.7.1, RCM is regarded as a corporate-level maintenance strategy that is designed to optimise the maintenance programme for the business. Reliability and availability are achieved by reducing the probability of system failure RCM is a super-strategy that includes all the other maintenance strategies, as shown in Figure 13.

RCM is defined as a tool that identifies productive and effective preventative maintenance chores for a piece of equipment with specific standard working instructions, for setting up intervals between maintenance.

- To quantify vertical roller mill maintenance cost through technical analysis.

The results of field data in 4.6.1 have proven that the best maintenance strategy for vertical roller mills' gearboxes is predictive maintenance. Data collection is the best tool to monitor the health or performance of the vertical roller mill. It has benefits such

as examination of current performance, identification of the root cause of the problem and examining the effectiveness of the solution.

- To determine the perceptions of vertical roller mill role players on the effects of maintenance on total availability and cost.

The maintenance costs of two vertical roller mills were discussed in Chapter 4. The organisation spent almost R5.55m on vertical roller mills' maintenance, mainly on gearboxes.

Table 5: Failure rate of vertical roller mills

Mill	**Location**	**2018**	**2019**	**2020**
Mill 1	White section	0.5	0.25	0.2
Mill 6	White section	1	0.33	0.25

The availability of two vertical roller mills decreased after implementation of predictive maintenance. High maintenance costs affect the EBIT of the organisation, which falls under operating costs or cash costs of the income statement. The maintenance budget is done every year and it does not always comply with the budget. If the company is spending more on maintenance, this affects budgeted profits for the year.

RCM is defined it as a process used to establish what actions must be taken to any piece of equipment to perform its intended function within its operating context. The results of RCM are the maintenance strategies to be implemented on each piece of equipment.

As stated in 2.7.1.1, RCM has the following advantages for the organisation:

- It is regarded as the most productive maintenance programme.
- It reduces maintenance costs by eliminating machinery overhauls.
- It reduces the rate of machinery downtime.
- It minimises equipment catastrophic failure.
- It maximises the reliability of the component/s.
- It involves the (RCFA).

Its attention is more on maintaining critical parts of the machinery

5.3 RECOMMENDATIONS

Vertical roller mills are too old. To minimise the number of breakdowns and stoppages, the correct maintenance strategy must be implemented. The success of the correct maintenance strategy relies on support from senior management, including the managing director. Management needs to make decisions on the availability of critical spare parts to be always available; therefore, management needs to adjust inventory to accommodate vertical roller mills' spare parts. The target of DWC must be reviewed by top management, which will allow the organisation to keep spares for vertical roller mills because the lead time is huge, and this has a huge impact on profits

Training of artisan operators is very crucial, which will assist them to do root cause analysis. Customer complaints must be communicated between engineering and production personnel so that they can come up with suggestions on how to solve the problem.

Predictive maintenance (vibration analysis) is proven to be best maintenance that must be implemented to minimise vertical roller mill downtime. Adjustments of 3mm made to the segments, and modification of the split ring mounted to the gearbox made a huge difference. The results of the oil analysis are clear without a trace of contamination.

It has been proven that predictive maintenance has the following benefits:

- Reduced maintenance costs.
- Reduced machine downtime.
- Reduced maintenance repairs.
- Reduced spare parts.
- Maximised life span of the machine.
- Increased operator safety.
- It verifies repairs of the machine.
- Maximised overall profits.

5.4 CONCLUSION

Based on the field data results and questionnaire analysis, it has been proven that the best maintenance strategy must be implemented. Predictive is the best strategy to

improve reliability and availability of vertical roller mills. The spare part is crucial for every business to ensure the smooth operation of the critical equipment. In the mining industry, critical spares are kept to reduce the financial and commercial cost of downtime This study will benefit the organisation, and the same process can be applied to other operations within the ZIMCO group.

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APPENDIX A

Data collection instrument

First read through the informed consent form, ask the person whether it is okay to continue with the interview and whether the interview may be recorded for accurate transcription.

1. In which department do you work?
2. Tell me about your experience and knowledge of the effects of maintenance on vertical roller mills. Please expand.
3. What can you tell me about the vertical roller mills we use? (Prod participant about issues such as operations, cost, efficiency, downtime, etc., whichever fall in his/her area of expertise)
4. Tell me about the maintenance strategy that is performed on vertical roller mills. (Prod with terms like how often, preventive, corrective… Also, ask whether he/she thinks this is optimal).
5. What do you know about the computer maintenance management system on vertical roller mills?
6. Tell me about the suppliers of mills and of spares for vertical roller mills.
7. What is your experience of fault-tracking (root cause analysis) on vertical roller mill failures?
8. To what extent are you informed of issues like production loss, customer complaints and quality issues caused by vertical roller mills? Comment on our communication during/after maintenance in general.
9. Tell me what you think about the production and financial effects of vertical roller mill failure and maintenance.
10. Are there any other issues that we overlook that we should rather consider than looking at the effects of maintenance on vertical roller mills?
11. If you could change anything to make the mills (and the maintenance of these mills) more efficient, what would that be? Please expand.
12. Is there anything else you would like to mention or discuss?

Thank you for your valuable inputs. I truly appreciate your time.

APPENDIX B

Quality statistics in tons

Year	Passed product	Rework	Scrap
2018	73100	393	246
2019	78033	172	291
2020	62833	278	219

APPENDIX C

Failure rate of vertical roller mills

Vertical roller mill failures

Mill	Location	2018	2019	2020
Mill 1	White section	2	4	5
Mill 6	White section	1	3	4
Total		3	7	9

Calculation of vertical roller mill failure rate

Failure rate per year = 1/ frequency of vertical roller mill per year. e.g., Year 1 (2018) = 1 / 2 = 0.5

Mill	Location	2018	2019	2020
Mill 1	White section	0.5	0.25	0.2
Mill 6	White section	1	0.33	0.25